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Tomioka et al.

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(45) **Date of Patent: Feb. 13, 2018**

(54) **VARIABLE MAGNIFICATION OPTICAL SYSTEM AND IMAGING APPARATUS**

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(73) Assignee: **FUJIFILM Corporation**, Tokyo (JP)

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(51) **Int. Cl.**

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G02B 15/28	(2006.01)
G02B 15/173	(2006.01)
G02B 15/24	(2006.01)
G02B 13/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 15/20*** (2013.01); ***G02B 13/009*** (2013.01); ***G02B 15/16*** (2013.01); ***G02B 15/173*** (2013.01); ***G02B 15/24*** (2013.01); ***G02B 15/28*** (2013.01)

(58) **Field of Classification Search**

CPC G02B 15/00; G02B 15/14; G02B 15/15; G02B 15/16; G02B 15/20; G02B 15/22; G02B 15/24; G02B 15/28; G02B 13/009

USPC 359/676–679, 683–687, 689–690, 359/694–706

See application file for complete search history.

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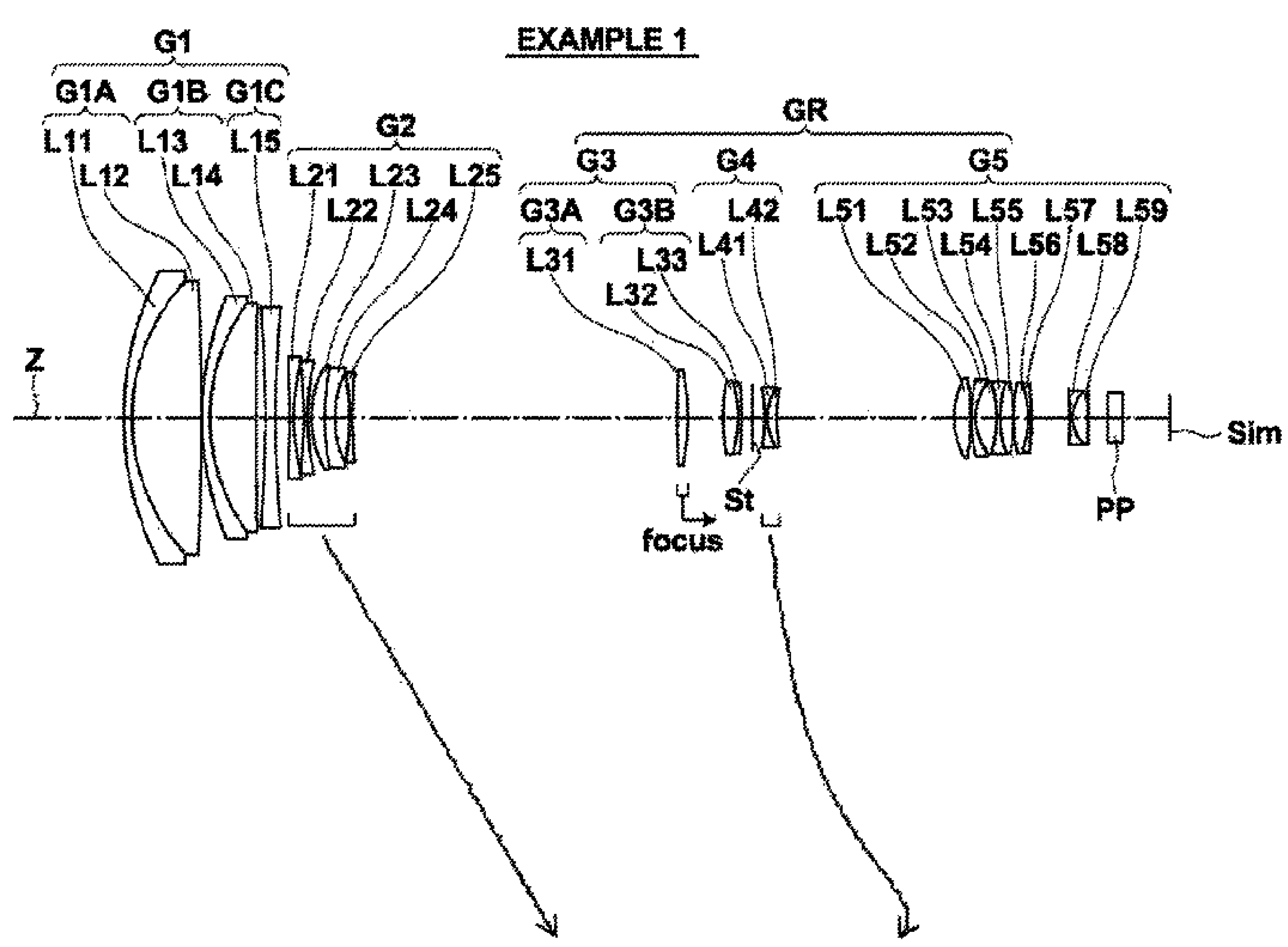
(57) **ABSTRACT**

A variable magnification optical system includes, in order from the object side: a positive first lens group, which is fixed when changing magnification; a negative second lens group that moves from the object side to the image side when changing magnification from the wide angle end to the telephoto end; and a rearward lens group having a positive refractive power throughout the entire variable magnification range that includes at least one lens group that moves when changing magnification. The first lens group includes, in order from the object side, a positive first lens group front group, a positive first lens group middle group, and a first lens group rear group constituted by a negative lens. The first lens group front group and first lens group middle group include cemented lenses formed by cementing a negative lens and a positive lens, provided in this order from the object side, together.

18 Claims, 16 Drawing Sheets



EXAMPLE 1

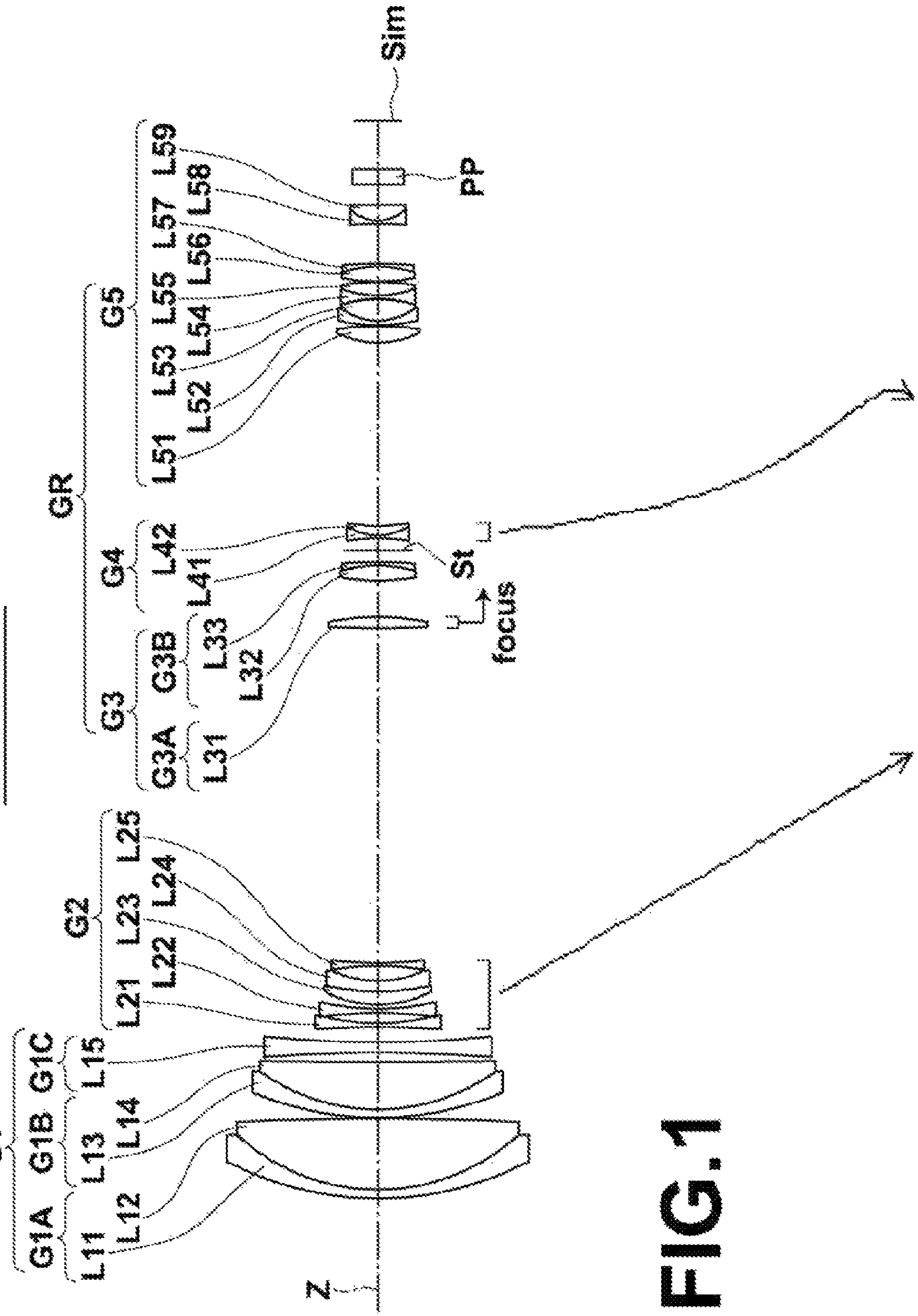


FIG.1

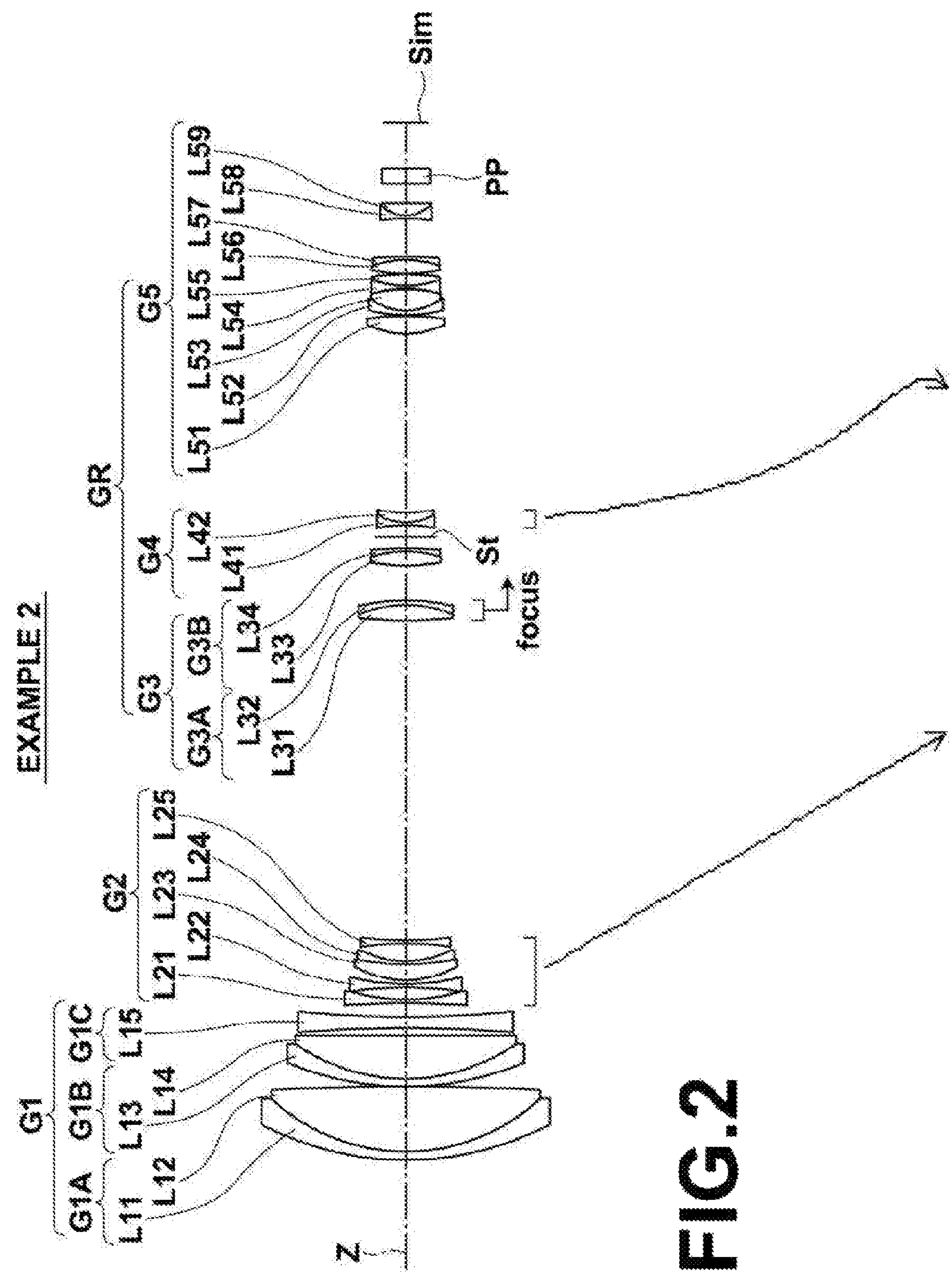

EXAMPLE 2
G1
G1A
G1B
G1C
L11
L12
L13
L14
L15
G2
L21
L22
L23
L24
L25
GR
G3
G3A
G3B
L31
L32
L33
L34
G4
L41
L42
G5
L51
L52
L53
L54
L55
L56
L57
L58
L59
St
focus
PP
Sim
Z

FIG.2

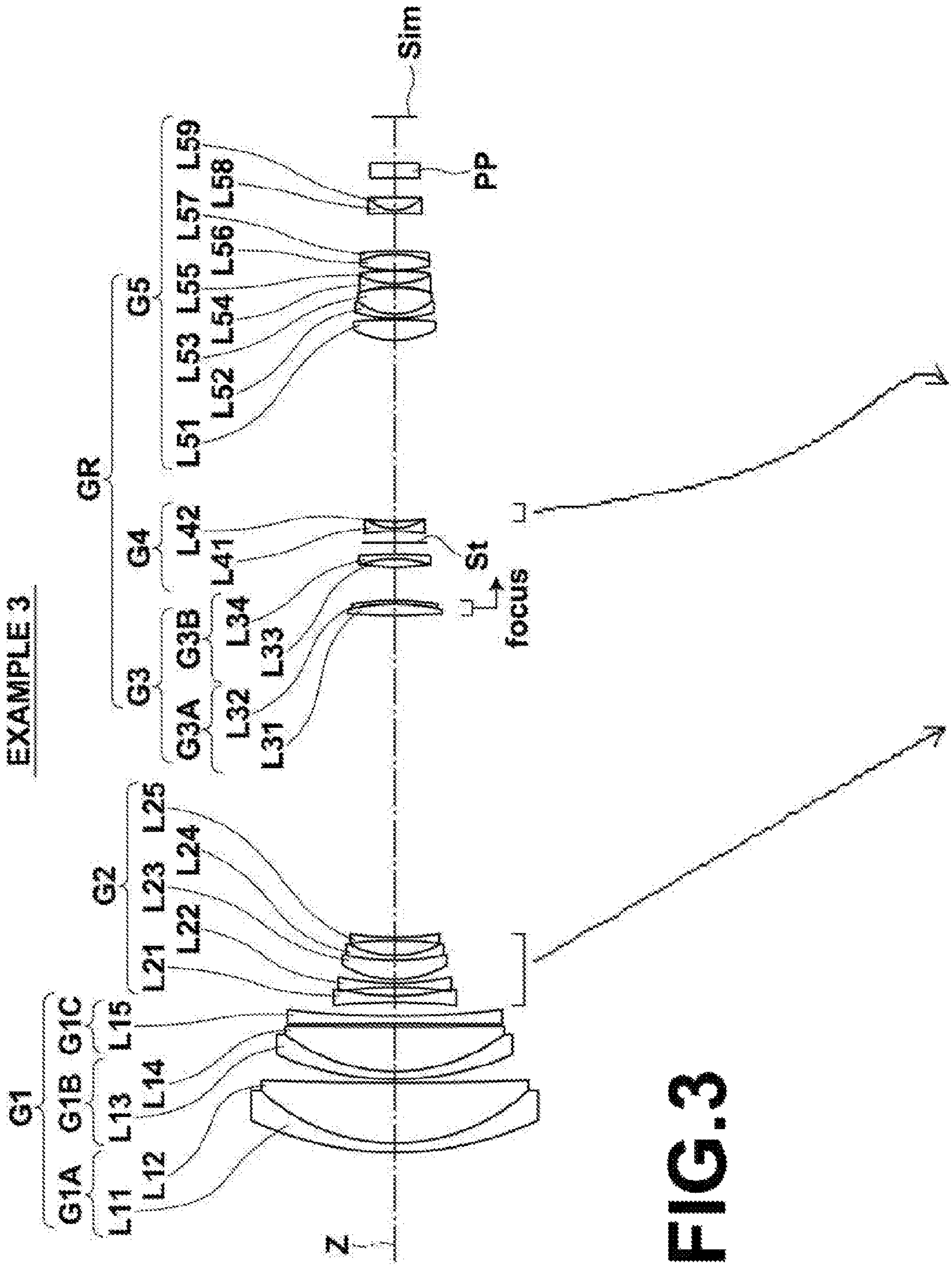

EXAMPLE 3
G1
G1A
G1B
G1C
L11
L12
L13
L14
L15
G2
L21
L22
L23
L24
L25
GR
G3
G3A
G3B
L31
L32
L33
L34
G4
L41
L42
St
focus
G5
L51
L52
L53
L54
L55
L56
L57
L58
L59
PP
Sim
Z

FIG.3

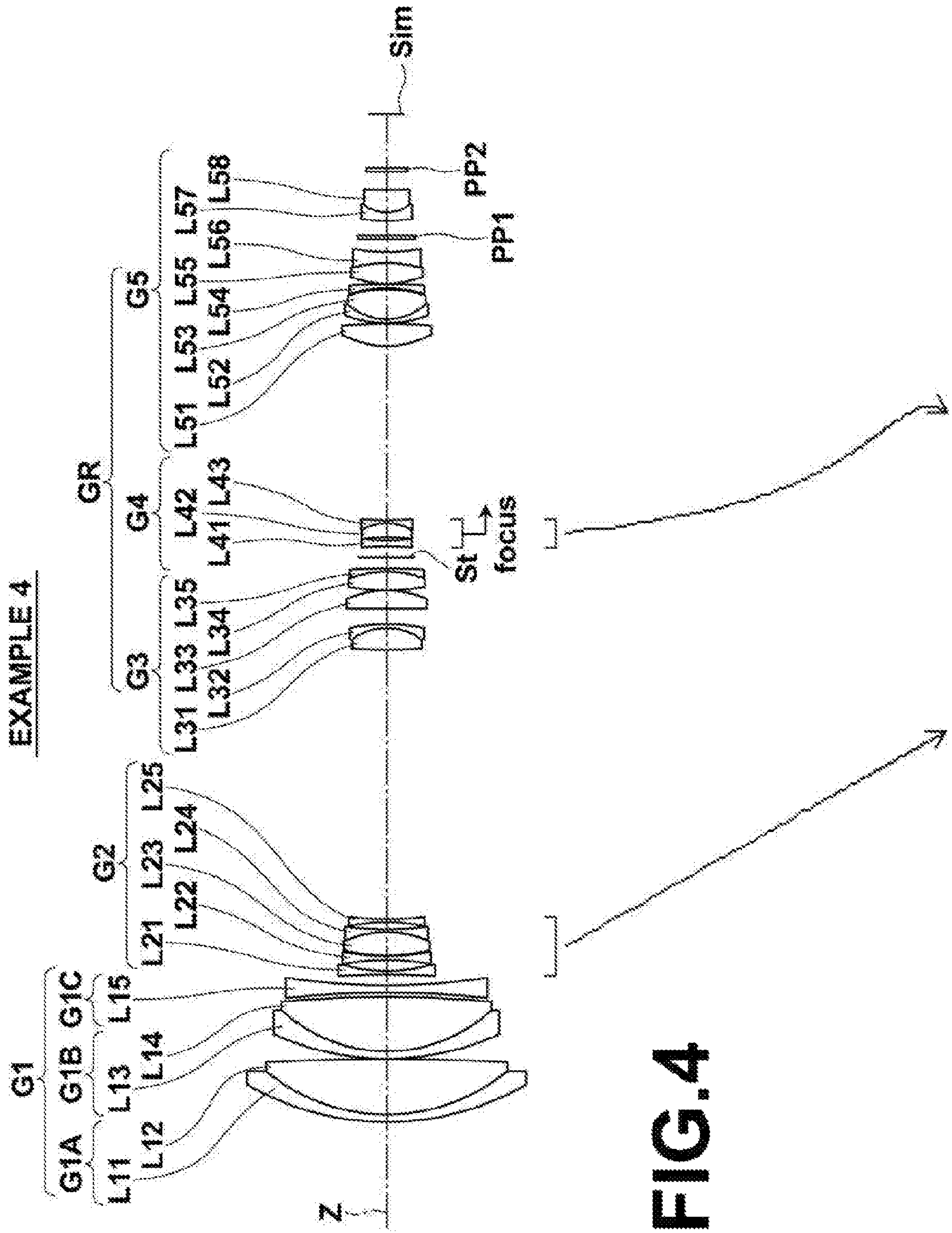

EXAMPLE 4
G1
G1A
G1B
G1C
L11
L12
L13
L14
L15
G2
L21
L22
L23
L24
L25
GR
G3
L31
L32
L33
L34
L35
G4
L41
L42
L43
St
focus
G5
L51
L52
L53
L54
L55
L56
L57
L58
PP1
PP2
Sim
Z

FIG.4

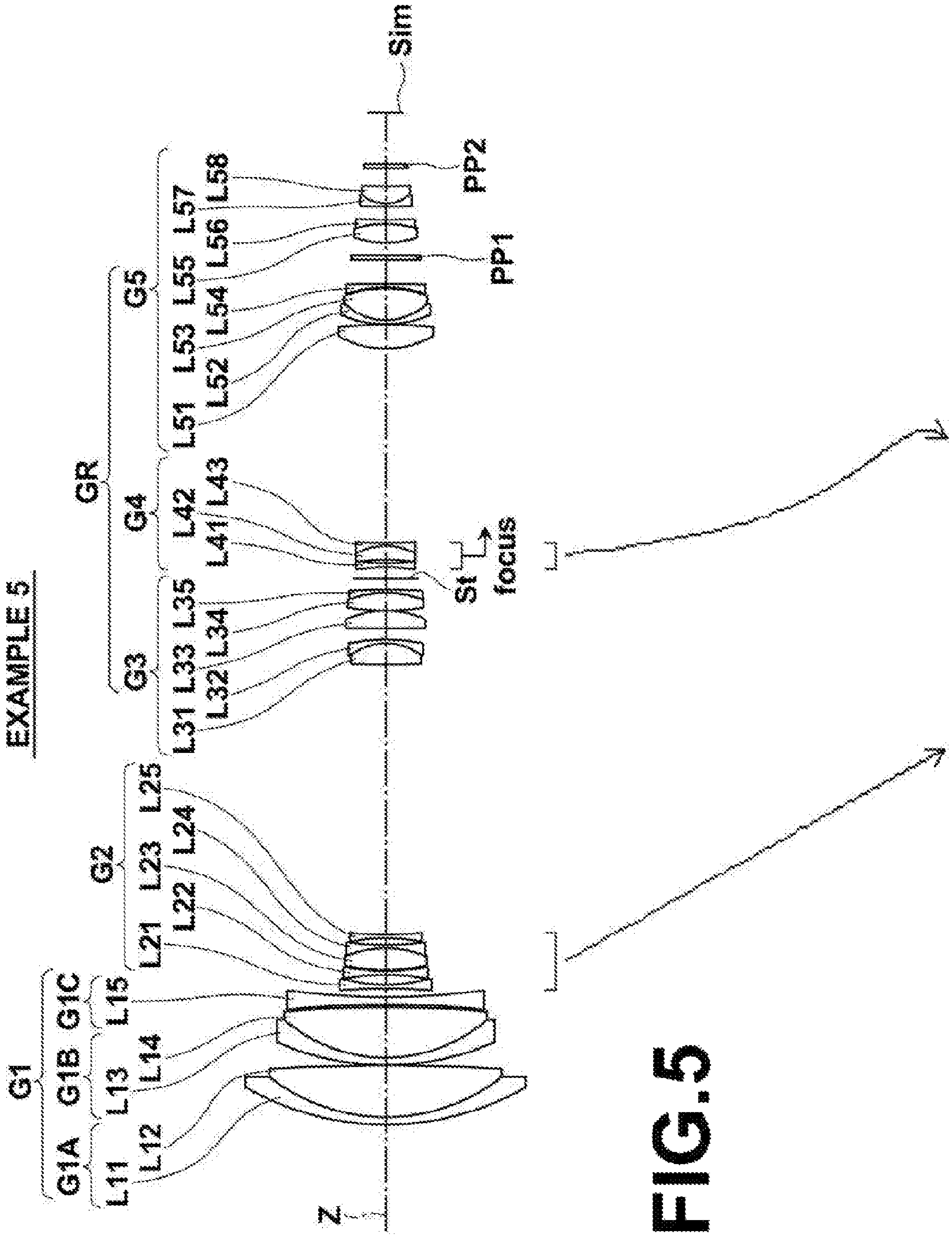

EXAMPLE 5
G1
G1A
G1B
G1C
L11
L12
L13
L14
L15
G2
L21
L22
L23
L24
L25
GR
G3
L31
L32
L33
L34
L35
G4
L41
L42
L43
St
focus
G5
L51
L52
L53
L54
L55
L56
L57
L58
PP1
PP2
Sim
Z

FIG.5

EXAMPLE 6

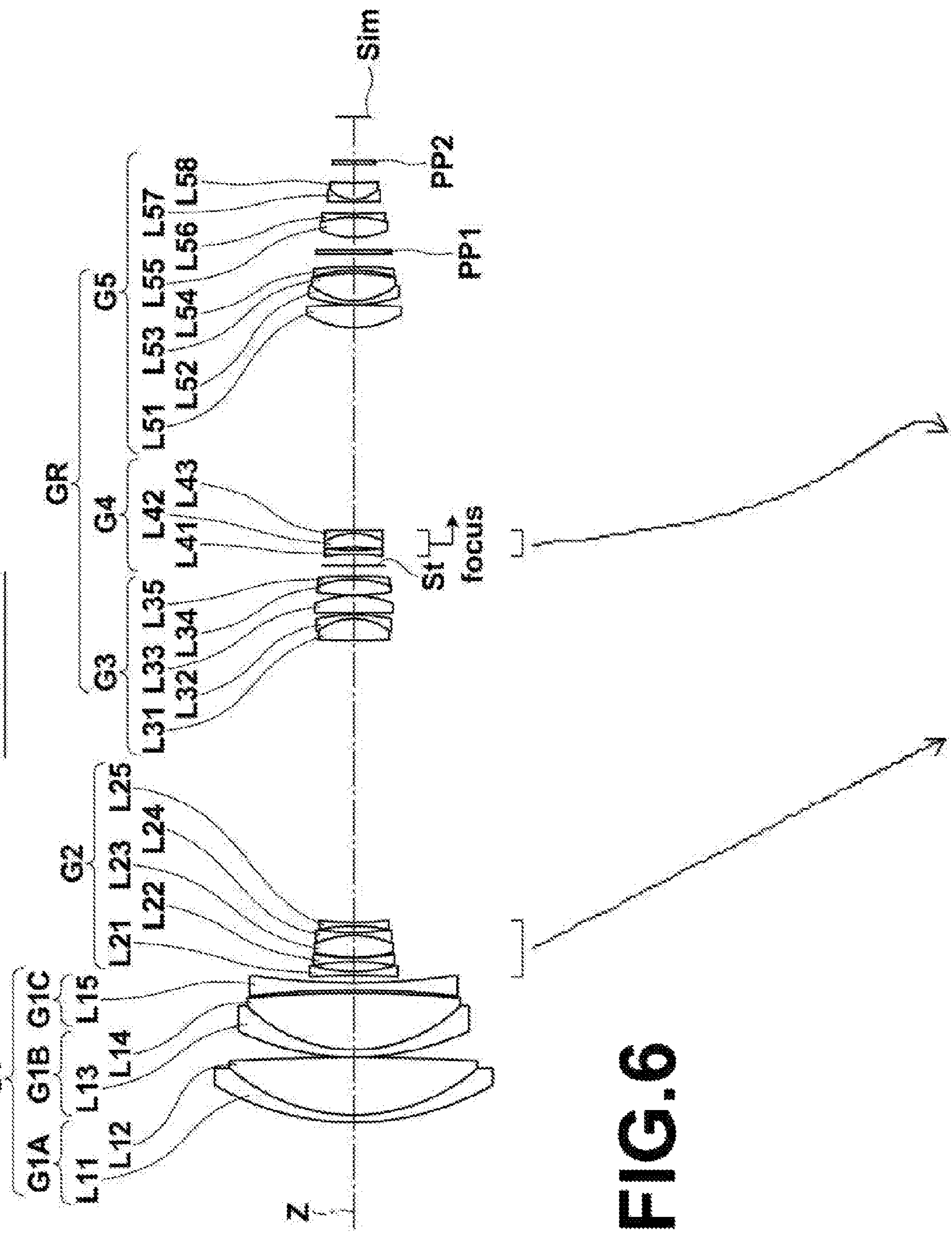


FIG.6

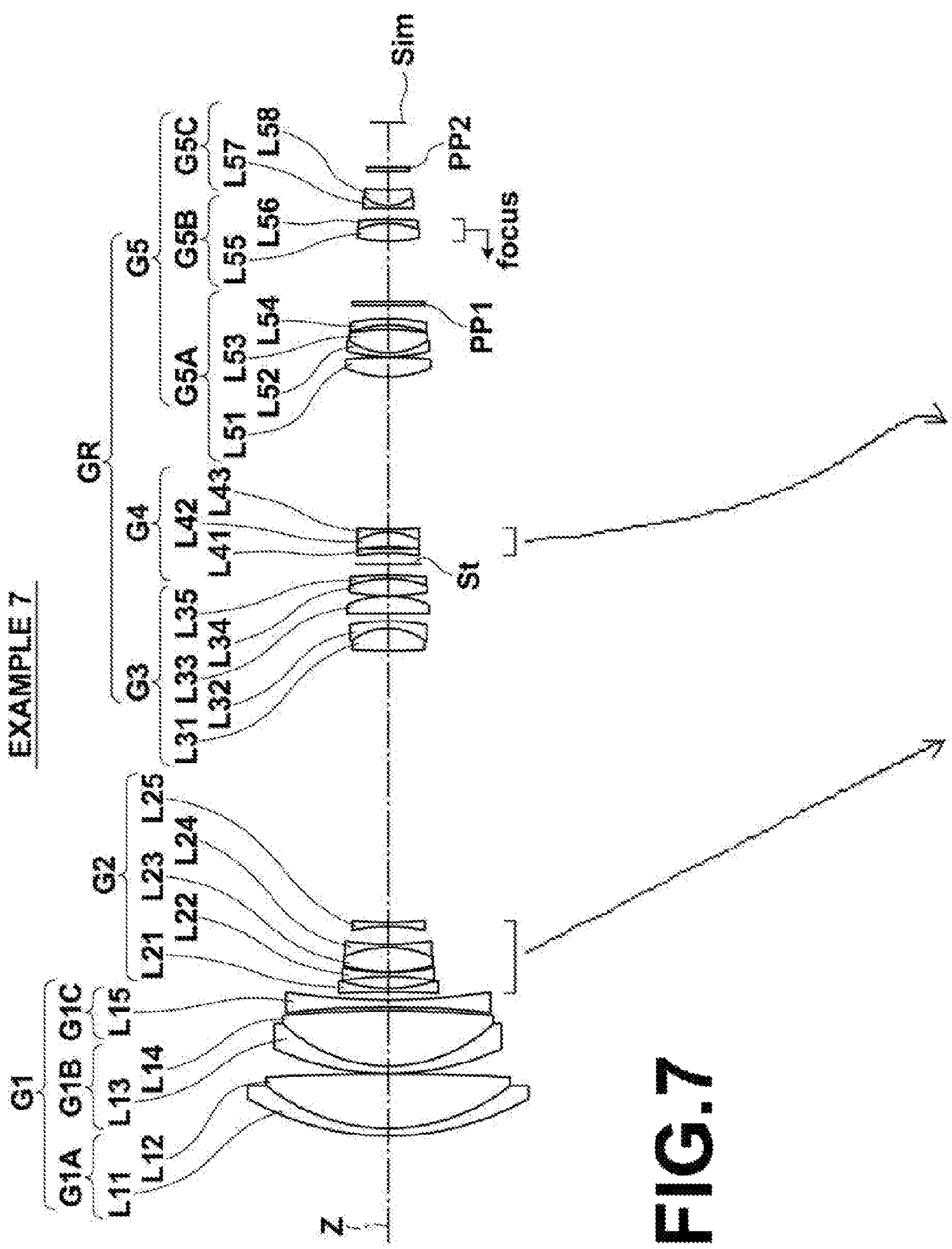

EXAMPLE 7
G1
G1A
G1B
G1C
L11
L12
L13
L14
L15
G2
L21
L22
L23
L24
L25
GR
G3
L31
L32
L33
L34
L35
G4
L41
L42
L43
St
G5
G5A
L51
L52
L53
L54
PP1
G5B
L55
L56
focus
G5C
L57
L58
PP2
Sim
Z

FIG.7

FIG.8

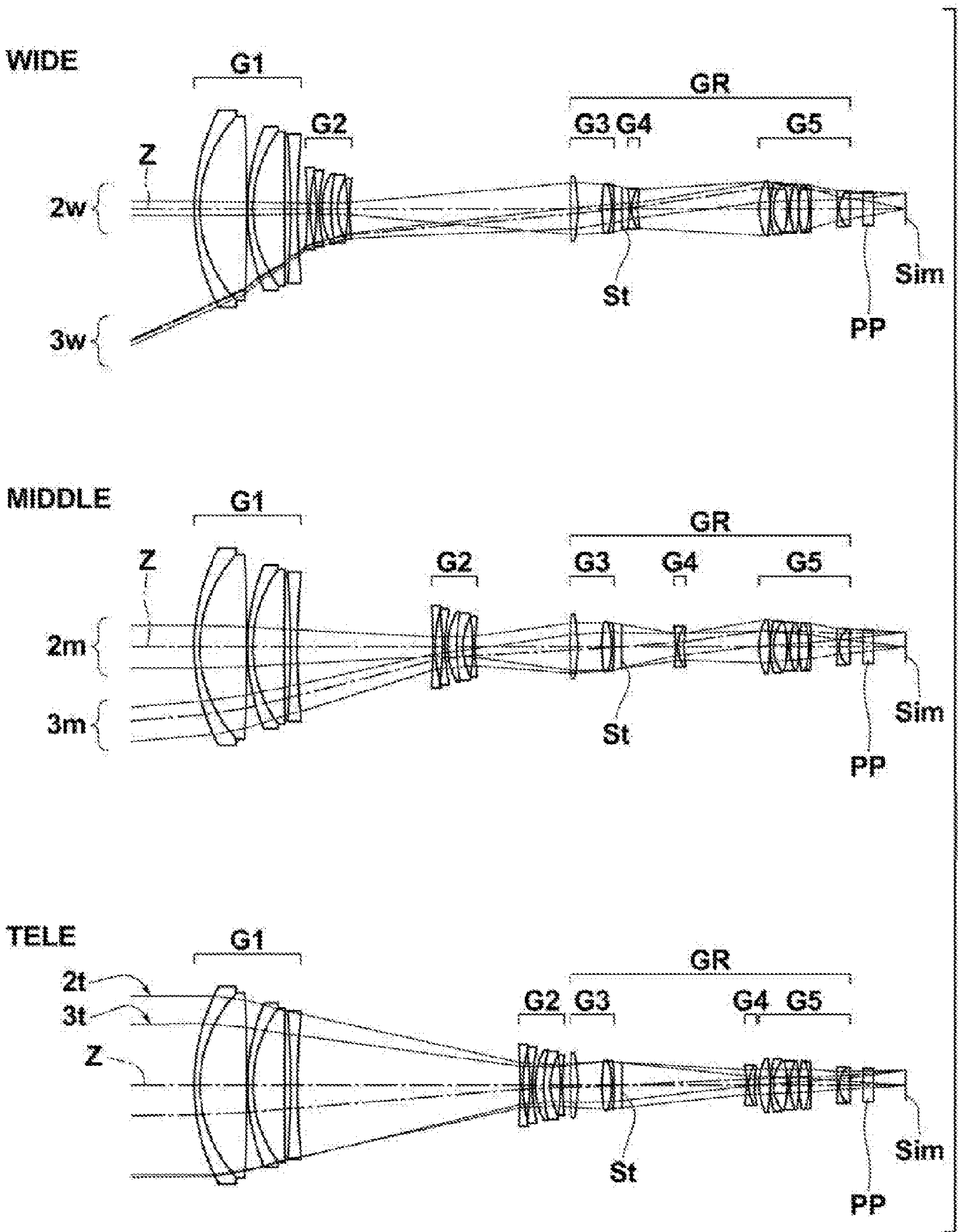

WIDE
G1
GR
G2
G3 G4
G5
Z
2w
3w
St
Sim
PP
MIDDLE
G1
GR
Z
G2
G3
G4
G5
2m
3m
St
Sim
PP
TELE
G1
GR
2t
3t
Z
G2 G3
G4 G5
St
Sim
PP

FIG.9

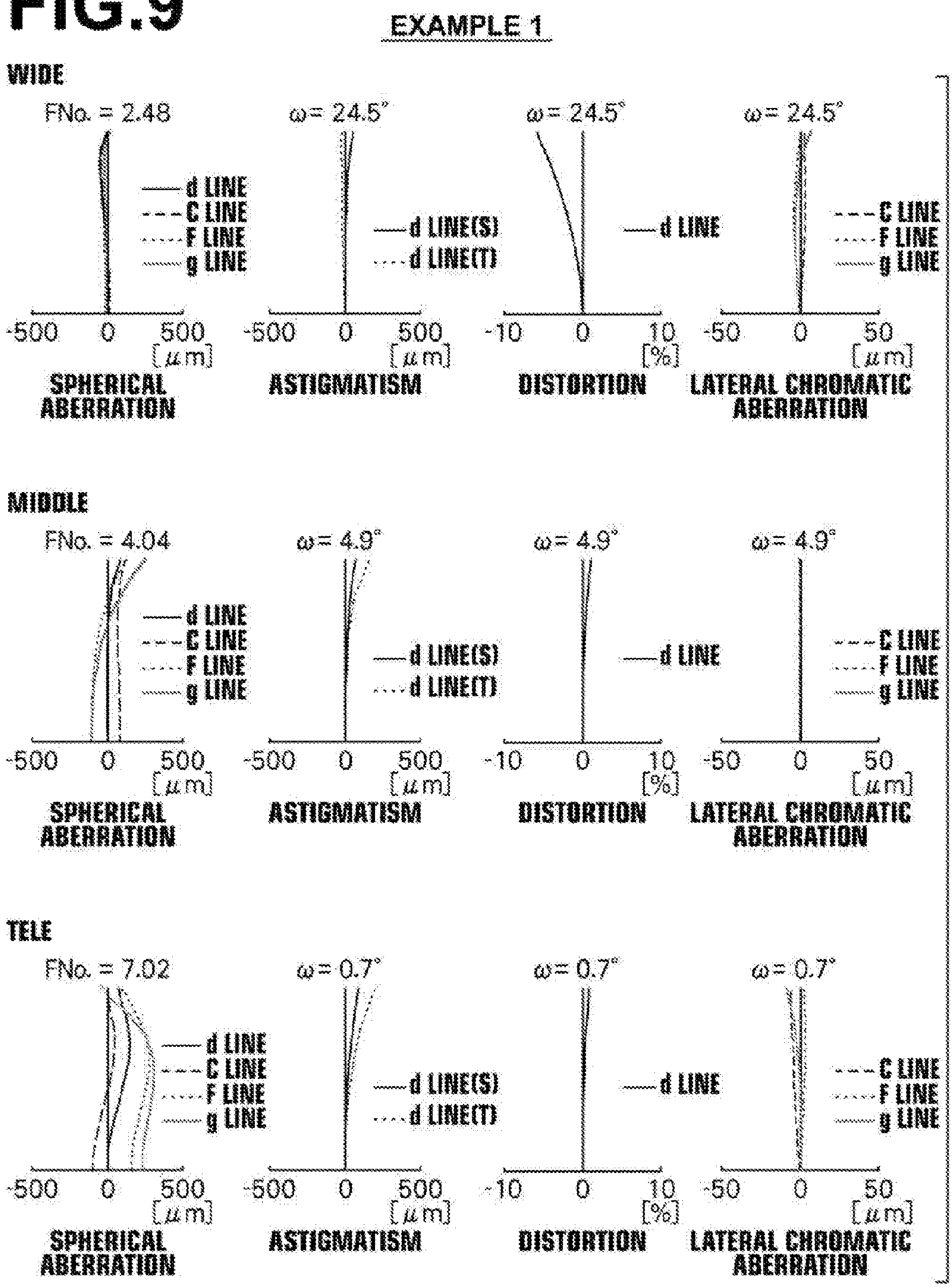

EXAMPLE 1
WIDE
FNo. = 2.48
ω= 24.5°
ω= 24.5°
ω= 24.5°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
SPHERICAL ABERRATION
-500 0 500 [μm]
ASTIGMATISM
-10 0 10 [%]
DISTORTION
-50 0 50 [μm]
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 4.04
ω= 4.9°
ω= 4.9°
ω= 4.9°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
SPHERICAL ABERRATION
-500 0 500 [μm]
ASTIGMATISM
-10 0 10 [%]
DISTORTION
-50 0 50 [μm]
LATERAL CHROMATIC ABERRATION
TELE
FNo. = 7.02
ω= 0.7°
ω= 0.7°
ω= 0.7°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
SPHERICAL ABERRATION
-500 0 500 [μm]
ASTIGMATISM
-10 0 10 [%]
DISTORTION
-50 0 50 [μm]
LATERAL CHROMATIC ABERRATION

FIG.10

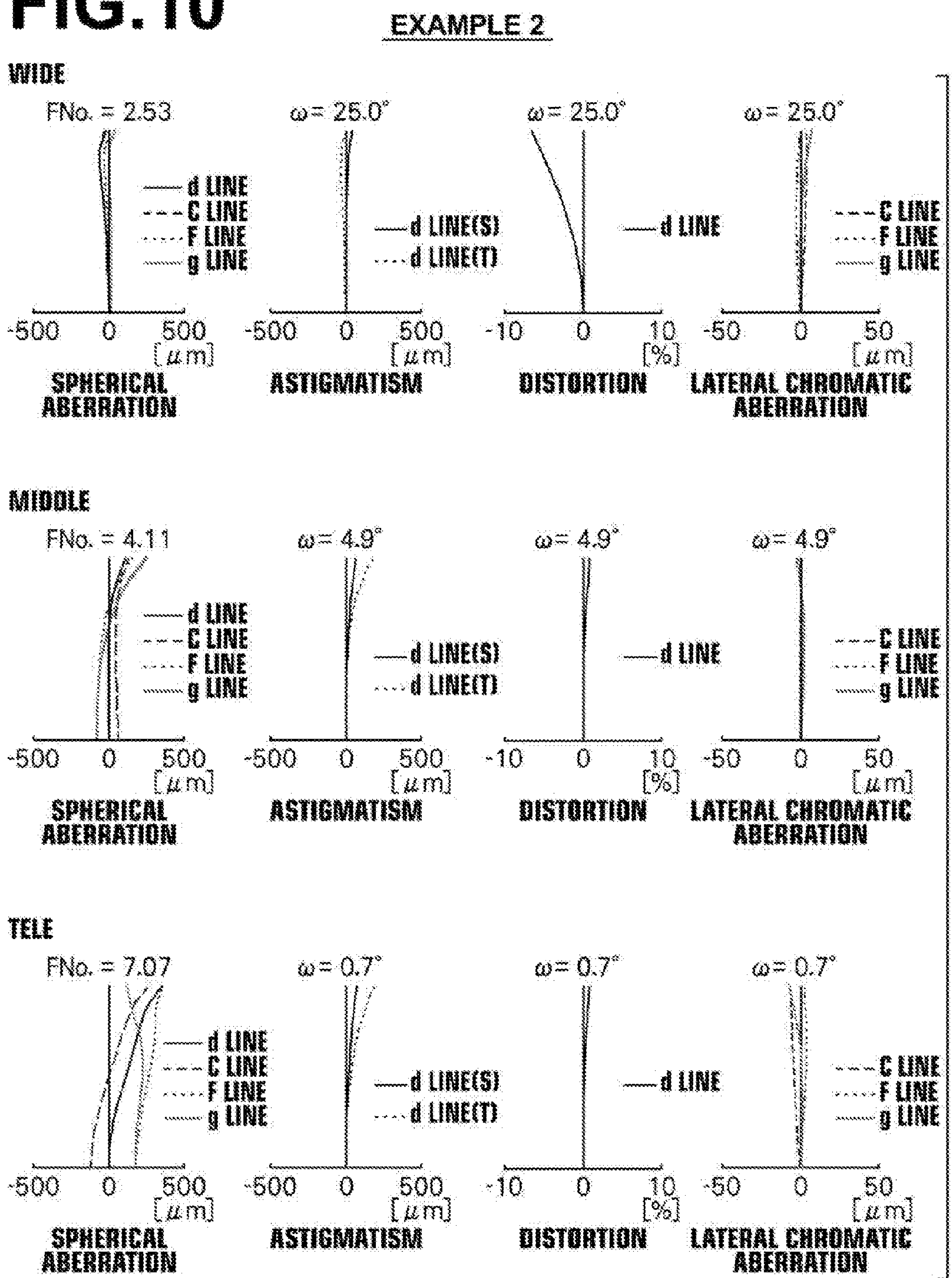

EXAMPLE 2
WIDE
FNo. = 2.53
ω= 25.0°
ω= 25.0°
ω= 25.0°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 4.11
ω= 4.9°
ω= 4.9°
ω= 4.9°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
TELE
FNo. = 7.07
ω= 0.7°
ω= 0.7°
ω= 0.7°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION

FIG.11

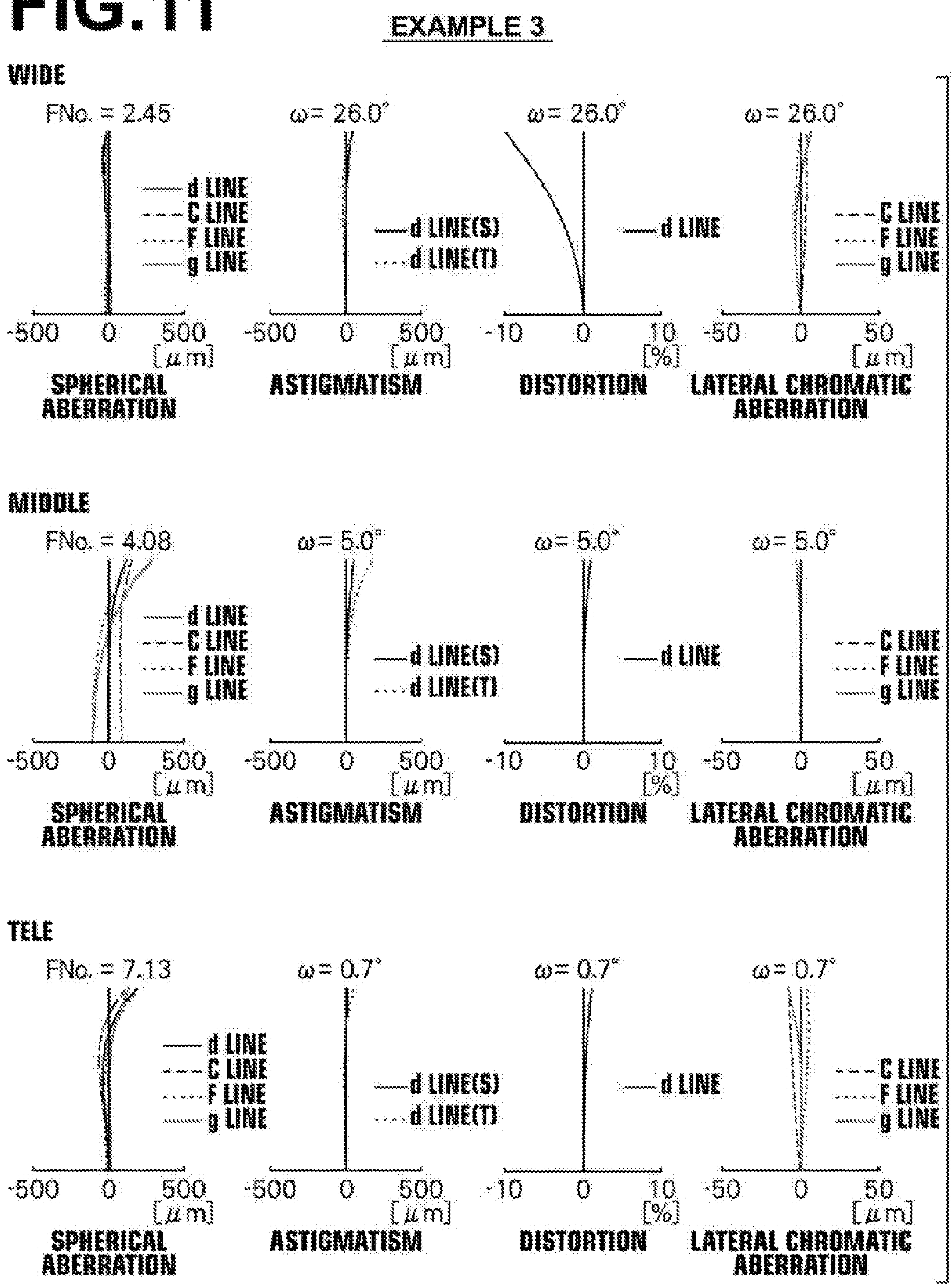

EXAMPLE 3
WIDE
FNo. = 2.45
ω= 26.0°
ω= 26.0°
ω= 26.0°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 4.08
ω= 5.0°
ω= 5.0°
ω= 5.0°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
TELE
FNo. = 7.13
ω= 0.7°
ω= 0.7°
ω= 0.7°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION

FIG.12

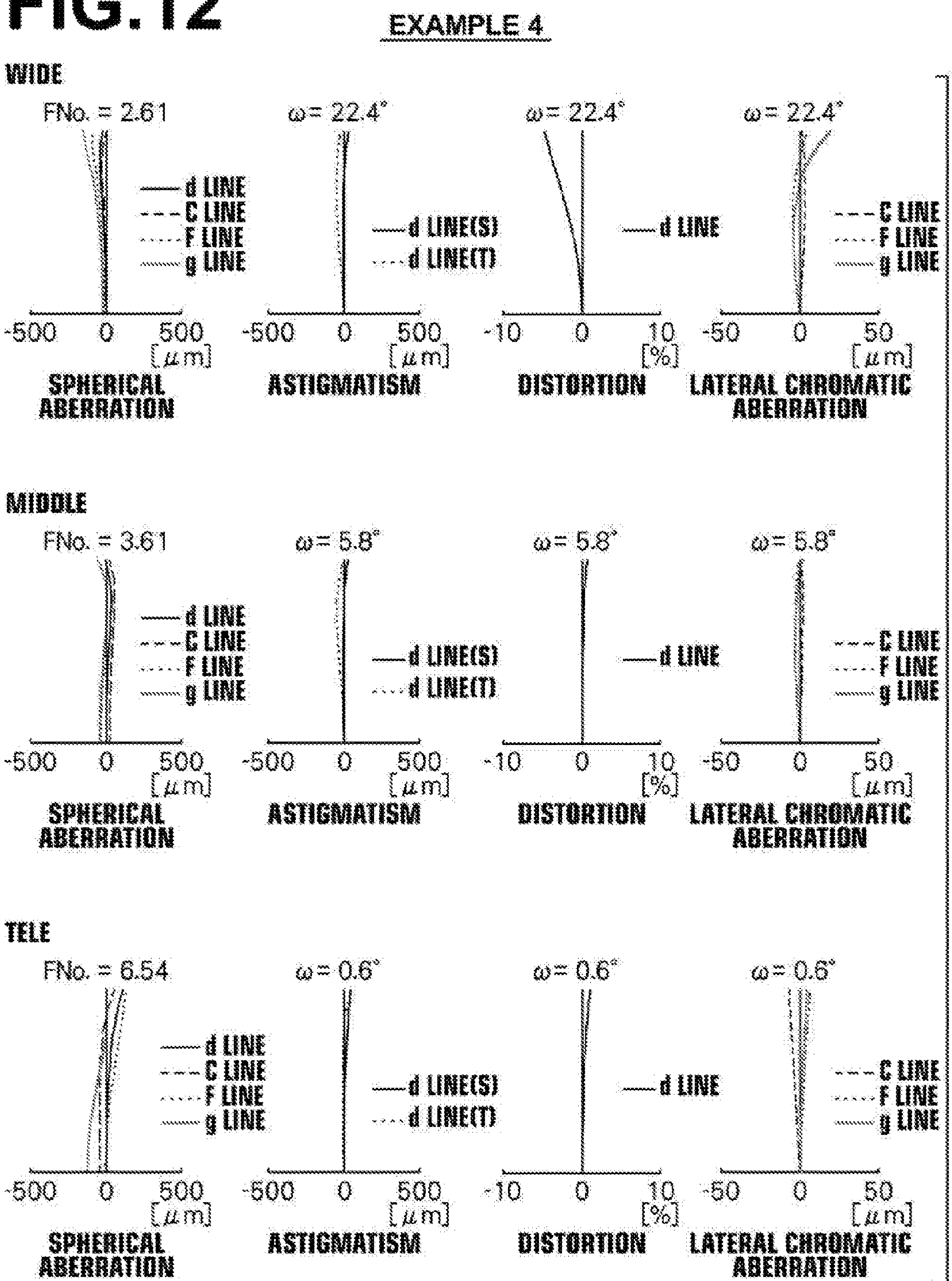

EXAMPLE 4
WIDE
FNo. = 2.61
ω= 22.4°
ω= 22.4°
ω= 22.4°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
SPHERICAL ABERRATION
-500 0 500 [μm]
ASTIGMATISM
-10 0 10 [%]
DISTORTION
-50 0 50 [μm]
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 3.61
ω= 5.8°
ω= 5.8°
ω= 5.8°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
SPHERICAL ABERRATION
-500 0 500 [μm]
ASTIGMATISM
-10 0 10 [%]
DISTORTION
-50 0 50 [μm]
LATERAL CHROMATIC ABERRATION
TELE
FNo. = 6.54
ω= 0.6°
ω= 0.6°
ω= 0.6°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
SPHERICAL ABERRATION
-500 0 500 [μm]
ASTIGMATISM
-10 0 10 [%]
DISTORTION
-50 0 50 [μm]
LATERAL CHROMATIC ABERRATION

FIG.13

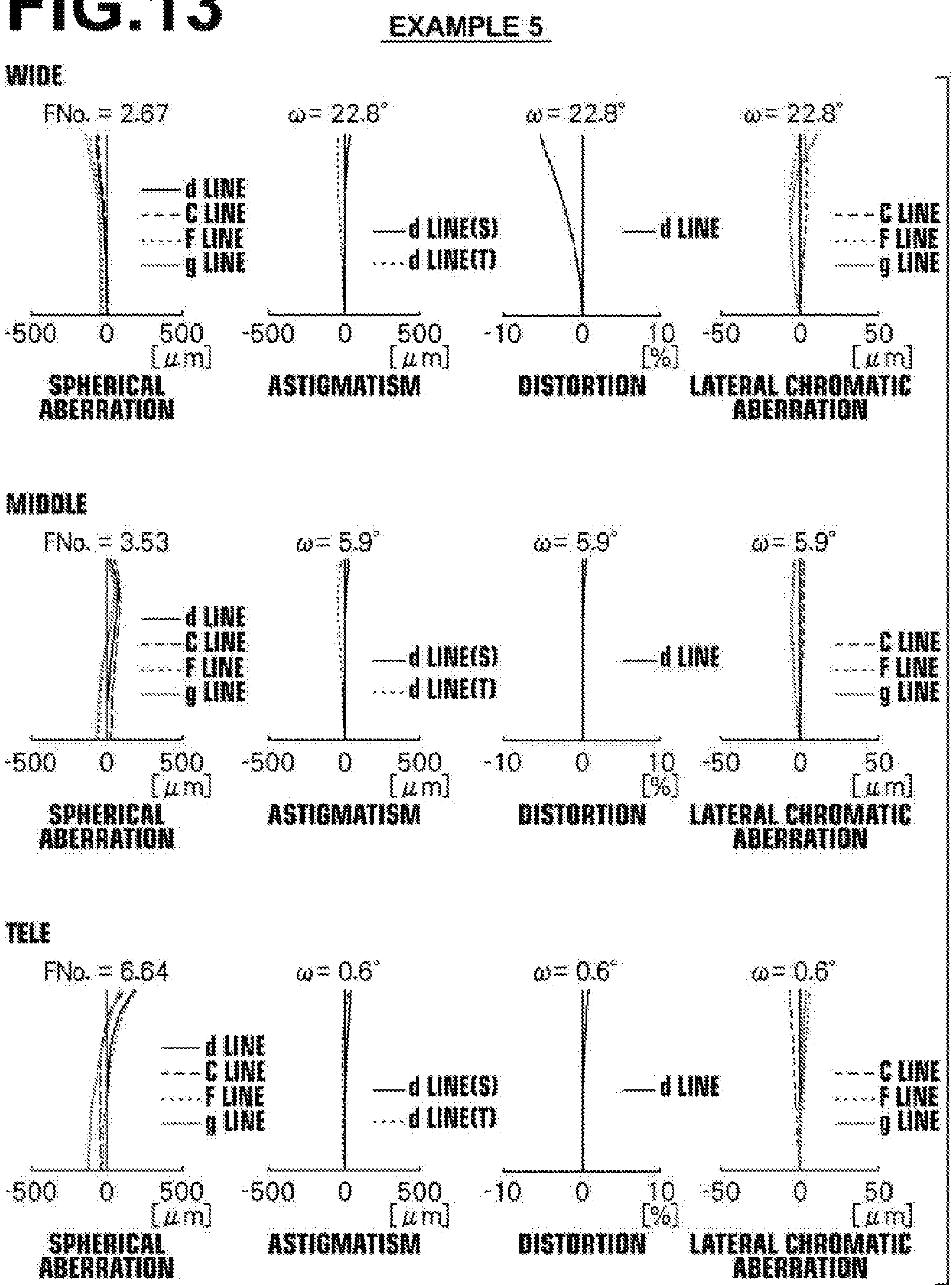

EXAMPLE 5
WIDE
FNo. = 2.67
ω= 22.8°
ω= 22.8°
ω= 22.8°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
-500
0
500
[μm]
-10
10
[%]
-50
50
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 3.53
ω= 5.9°
TELE
FNo. = 6.64
ω= 0.6°

FIG.14

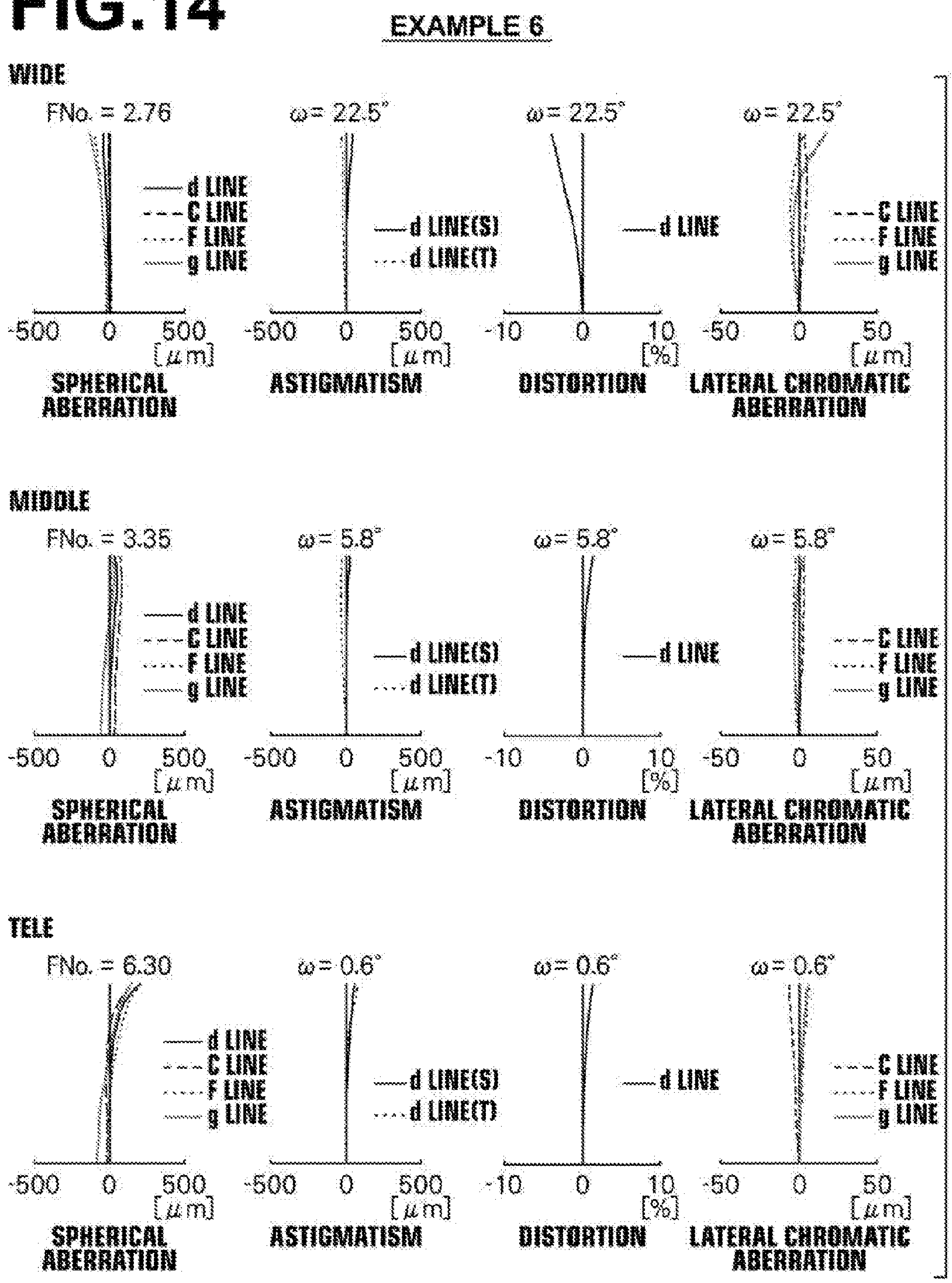

EXAMPLE 6
WIDE
FNo. = 2.76
ω= 22.5°
ω= 22.5°
ω= 22.5°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 3.35
ω= 5.8°
ω= 5.8°
ω= 5.8°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
TELE
FNo. = 6.30
ω= 0.6°
ω= 0.6°
ω= 0.6°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
d LINE
C LINE
F LINE
g LINE
-500 0 500 [μm]
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION

FIG.15

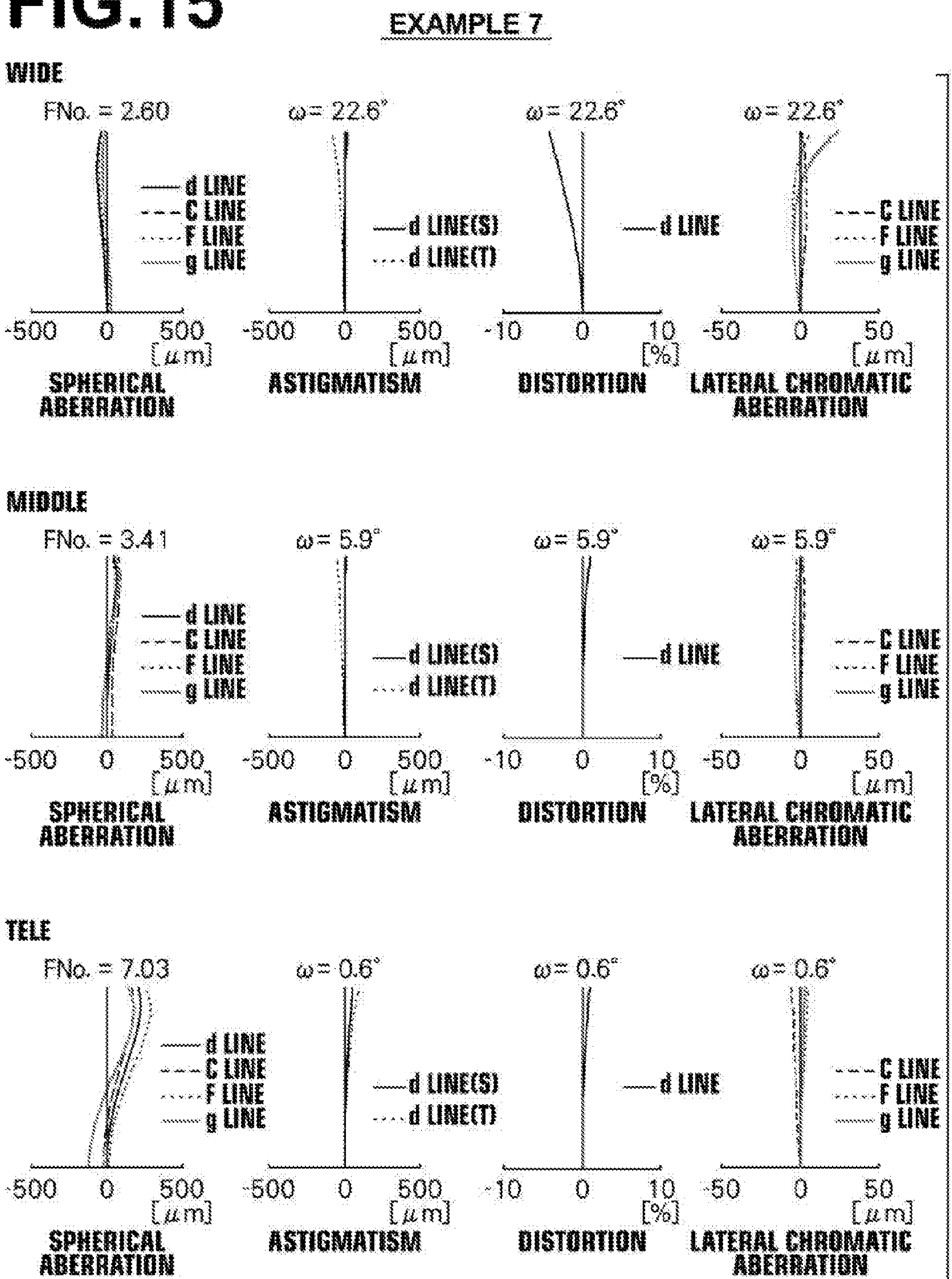
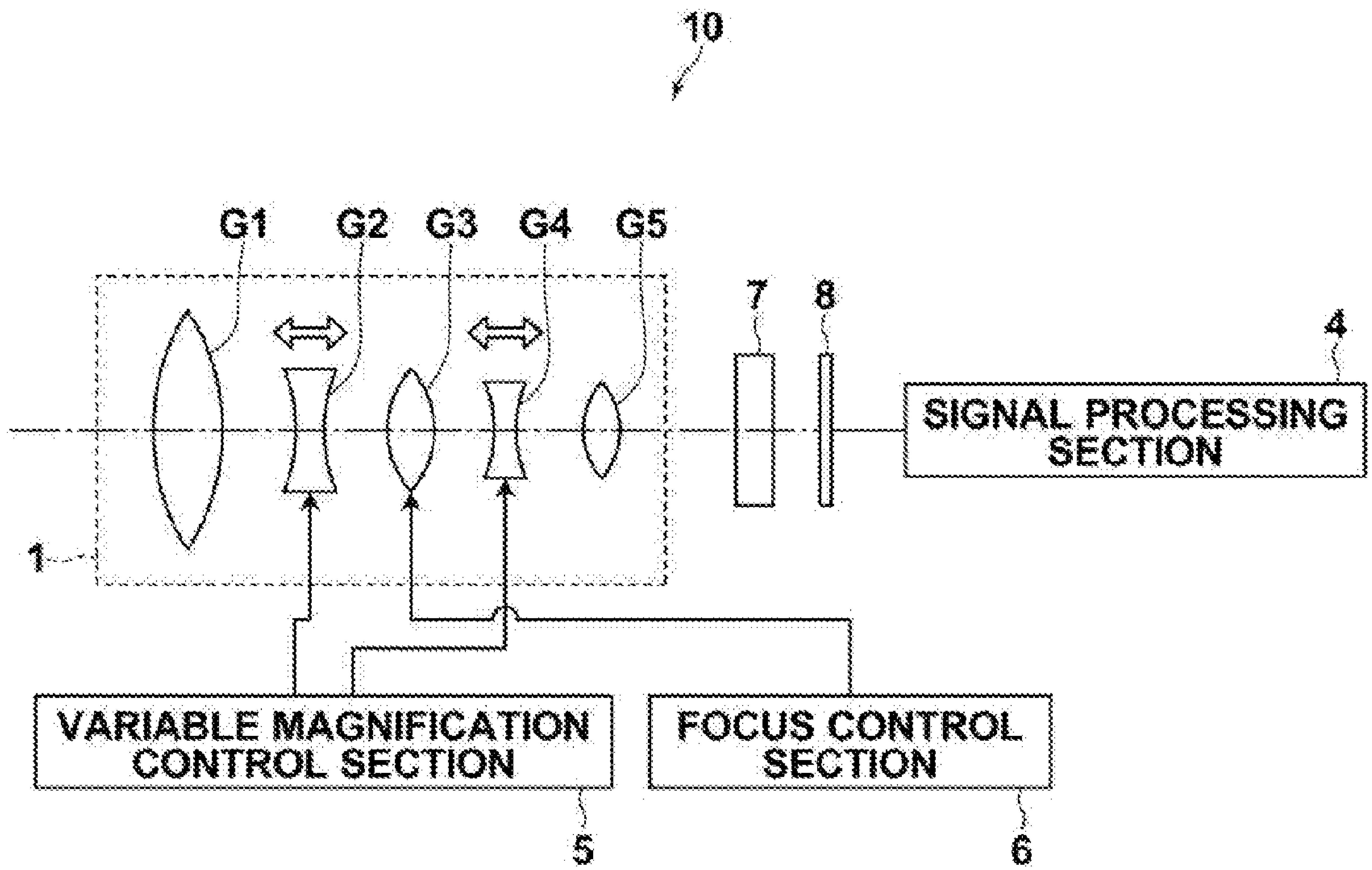

EXAMPLE 7
WIDE
FNo. = 2.60
ω= 22.6°
d LINE
C LINE
F LINE
g LINE
d LINE(S)
d LINE(T)
-500 0 500 [μm]
-10 0 10 [%]
-50 0 50 [μm]
SPHERICAL ABERRATION
ASTIGMATISM
DISTORTION
LATERAL CHROMATIC ABERRATION
MIDDLE
FNo. = 3.41
ω= 5.9°
TELE
FNo. = 7.03
ω= 0.6°

FIG.16


10
G1
G2
G3
G4
G5
7
8
4
SIGNAL PROCESSING SECTION
1
VARIABLE MAGNIFICATION CONTROL SECTION
FOCUS CONTROL SECTION
5
6

VARIABLE MAGNIFICATION OPTICAL SYSTEM AND IMAGING APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority under 35 U.S.C. §119 to Japanese Patent Application No. 2015-148416 filed on Jul. 28, 2015. The above application is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND

The present disclosure is related to a variable magnification optical system and an imaging apparatus. More particularly, the present disclosure is related to a variable magnification optical system which is favorably suited for use in long distance surveillance cameras, and to an imaging apparatus equipped with the variable magnification optical system.

Conventionally, surveillance cameras are employed to prevent crime, to record scenes, etc., and the number thereof is increasing recently. Variable magnification optical systems are preferably utilized as lens systems for surveillance cameras in scenes that require high general use properties. Among such variable magnification optical systems, there is a trend for configurations in which the lens group provided most toward the object side does not move when changing magnification to be preferred. Known variable magnification optical systems in which the lens group provided most toward the object side are fixed when changing magnification are disclosed in Japanese Unexamined Patent Publication Nos. H9(1997)-325269 and H4(1992)-191811, for example.

SUMMARY

Long distance surveillance cameras had conventionally been employed at ports, airports, etc. Recently, there is growing demand for long distance surveillance cameras for various uses. For this reason, there is demand for a variable magnification optical system having a high variable magnification ratio which is utilizable in long distance surveillance cameras. However, it cannot be said that the variable magnification ratios of the optical systems disclosed in Japanese Unexamined Patent Publication Nos. H9(1997)-325269 and H4(1992)-191811 are sufficient. Assuming a case in which the high variable magnification ratios of the optical systems disclosed in Japanese Unexamined Patent Publication Nos. H9(1997)-325269 and H4(1992)-191811 are increased, it would become difficult to suppress fluctuations in longitudinal chromatic aberration and distortion when changing magnification.

The present disclosure has been developed in view of the foregoing circumstances. The present disclosure provides a variable magnification optical system having a high variable magnification ratio and high optical performance. The present disclosure also provides an imaging apparatus equipped with this variable magnification optical system.

A variable magnification optical system of the present disclosure consists of, in order from the object side to the image side:

a first lens group having a positive refractive power, which is fixed with respect to an image formation plane when changing magnification;

a second lens group having a negative refractive power that moves from the object side to the image side when changing magnification from the wide angle end to the telephoto end; and

a rearward lens group having a positive refractive power throughout the entire variable magnification range that includes at least one lens group that moves when changing magnification, the distance between the rearward lens group and the second lens group changing when changing magnification;

the first lens group consisting of, in order from the object side to the image side, a first lens group front group having a positive refractive power, a first lens group middle group having a positive refractive power, and a first lens group rear group having a negative refractive power;

the first lens group front group consisting of a cemented lens formed by cementing a negative lens and a positive lens, provided in this order from the object side to the image side, together, the coupling surface of this cemented lens being convex toward the object side, and the surface most toward the object side within the first lens group front group being convex;

the first lens group middle group consisting of a cemented lens formed by cementing a negative lens and a positive lens, provided in this order from the object side to the image side, together, the coupling surface of this cemented lens being convex toward the object side, and the surface most toward the object side within the first lens group middle group being convex;

the first lens group rear group consisting of one negative lens; and

Conditional Formula (1) below being satisfied:

$$-50<fT/f2<-10 \tag{1}$$

wherein fT is the focal length of the entire optical system at the telephoto end, and f**2** is the focal length of the second lens group.

In the variable magnification optical system of the present disclosure, it is preferable for Conditional Formula (1-1) below to be satisfied, and further for Conditional Formula (1-2) to be satisfied, within the range that satisfies Conditional Formula (1) above.

$$-40<fT/f2<-10 \tag{1-1}$$

$$-40<fT/f2<-15 \tag{1-2}$$

In the variable magnification optical system of the present disclosure, it is preferable for at least one of Conditional Formulae (2) through (4) and (2-1) through (4-1) to be satisfied.

$$2<fT/f1<5 \tag{2}$$

$$-1.5<f1/f1C<-0.3 \tag{3}$$

$$0<(L1Cf+L1Cr)/(L1Cf-L1Cr)<0.95 \tag{4}$$

$$2.5<fT/f1<3.5 \tag{2-1}$$

$$-1<f1/f1C<-0.5 \tag{3-1}$$

$$0.05<(L1Cf+L1Cr)/(L1Cf-L1Cr)<0.5 \tag{4-1}$$

wherein fT is the focal length of the entire optical system at the telephoto end, f**1** is the focal length of the first lens group, f**1**C is the focal length of the first lens group rear group, L**1**Cf is the radius of curvature of the surface toward the object side of the negative lens of the first lens group rear group, and L1Cr is the radius of curvature of the surface toward the image side of the negative lens of the first lens group rear group.

In the variable magnification optical system of the present disclosure, it is preferable for Conditional Formulae (5) and (6) below to be satisfied. It is more preferable for at least one of Conditional Formulae (5-1) and (6-1) below to be satisfied, within the ranges that satisfy Conditional Formulae (5) and (6) below.

$$0<\nu Ap-\nu An<35 \quad (5)$$

$$60<(\nu Ap+\nu An)/2<90 \quad (6)$$

$$5<\nu Ap-\nu An<30 \quad (5\text{-}1)$$

$$65<(\nu Ap+\nu An)/2<80 \quad (6\text{-}1)$$

wherein νAp is the Abbe's number with respect to the d line of the positive lens within the first lens group front group, and νAn is the Abbe's number with respect to the d line of the negative lens within the first lens group front group.

In the variable magnification optical system of the present disclosure, the rearward lens group may consist of, in order from the object side to the image side, a third lens group having a positive refractive power which is fixed with respect to the image formation plane when changing magnification, a fourth lens group having a negative refractive power which moves when changing magnification, and a fifth lens group having a positive refractive power, the distance between the fourth lens group and the fifth lens group changing when changing magnification. In this case, it is preferable for a stop, which is fixed with respect to the image formation plane when changing magnification, to be provided. Also in this case, it is preferable for the fifth lens group to be fixed with respect to the image formation plane when changing magnification.

In the case that the rearward lens group consists of the third lens group through the fifth lens group described above, it is preferable for at least one of Conditional Formulae (7), (8), (7-1), and (8-1) below to be satisfied.

$$-1<\beta 5T<0 \quad (7)$$

$$1.15<\beta 4T/\beta 4W<3 \quad (8)$$

$$-0.6<\beta 5T<-0.2 \quad (7\text{-}1)$$

$$1.2<\beta 4T/\beta 4W<2 \quad (8\text{-}1)$$

wherein β5T is the transverse magnification ratio of the fifth lens group in a state focused on an object at infinity at the telephoto end, β4T is the transverse magnification ratio of the fourth lens group in a state focused on an object at infinity at the telephoto end, β4W is the transverse magnification ratio of the fourth lens group in a state focused on an object at infinity at the wide angle end.

An imaging apparatus of the present disclosure is equipped with the variable magnification optical system of the present disclosure.

Note that the phrases "consists of" and "consisting of" refers to essential elements. Lenses that practically do not have any power, optical elements other than lenses such as a cover glass and filters, and mechanical components such as lens flanges, a lens barrel, an imaging element, a camera shake correcting mechanism, etc., may also be included in addition to the constituent elements listed above.

Note that the expression "lens group" does not necessarily refer to those constituted by a plurality of lenses, and include groups which are constituted by a single lens.

Note that the signs of the refractive powers of each lens group, referred to as "first lens group having a positive refractive power" and the like, are the signs of the refractive indices of each of the lens groups as a whole. In addition, the refractive powers of each lens group are those in a state in which the variable magnification optical system is focused on an object at infinity, unless particularly noted. In addition, the signs of transverse magnification ratios are defined as follows. That is, in a cross section in the horizontal direction that includes the optical axis, when the signs of object heights and image heights above the optical axis are designated as being positive and the signs of object heights and image heights below the optical axis are designated as being negative, the sign of the transverse magnification is positive in the case that the object height and the image height are the same sign, and negative when the in the case that the object height and the image height are different signs.

Note that the signs of the refractive powers of the lens groups, the refractive powers of the lenses, the surface shapes of the lenses, and the values of the radii of curvature in the variable magnification optical system of the present disclosure are considered in the paraxial region in cases that aspherical surfaces are included. In addition, the signs of the radii of curvature are positive for shapes which are convex toward the object side, and negative for shapes which are convex toward the image side.

In the present disclosure, the configuration of the first lens group is set in detail and a predetermined conditional formula related to the refractive power of the second lens group is satisfied in a lens system constituted by, in order from the object side to the image side, the fixed positive first lens group, the moving negative second lens group, and the rearward lens group that includes a moving group and is positive throughout the entire variable magnification range. Therefore, a variable magnification optical system having a high variable magnification ratio and high optical performance, as well as an imaging apparatus equipped with this variable magnification optical system, can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 1 of the present disclosure.

FIG. **2** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 2 of the present disclosure.

FIG. **3** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 3 of the present disclosure.

FIG. **4** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 4 of the present disclosure.

FIG. **5** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 5 of the present disclosure.

FIG. **6** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 6 of the present disclosure.

FIG. **7** is a sectional diagram that illustrates the configuration of a variable magnification optical system according to Example 7 of the present disclosure.

FIG. **8** is a collection of sectional diagrams that illustrate the configuration of the variable magnification optical system of FIG. **1** as well as the paths of light beams that pass therethrough.

FIG. **9** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 1, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **10** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 2, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **11** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 3, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **12** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 4, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **13** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 5, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **14** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 6, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **15** is a collection of diagrams that illustrate various aberrations of the variable magnification optical system according to Example 7, wherein the diagrams illustrate spherical aberration, astigmatism, distortion, and lateral chromatic aberration in order from the left side of the drawing sheet.

FIG. **16** is a diagram that schematically illustrates the configuration of an imaging apparatus according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present disclosure will be described in detail with reference to the attached drawings. FIG. **1** through FIG. **7** are cross sectional diagrams that illustrate the configurations of variable magnification optical systems according to embodiments, each of which corresponds to Examples 1 through 7 to be described later. In FIG. **1** through FIG. **7**, the left side is the object side, and the right side is the image side. FIG. **1** through FIG. **7** illustrate lens configurations in a state focused on an object at infinity at the wide angle end. In addition, FIG. **8** illustrates the configurations of the example of FIG. **1** and light beams in each variable magnification state. In FIG. **8**, a state at the wide angle end is illustrated in the upper portion denoted "WIDE", a state in which the variable magnification optical system is in an intermediate focal point distance is illustrated in the middle portion denoted "MIDDLE", and a state at the telephoto angle end is illustrated in the upper portion denoted "TELE". FIG. **8** illustrates an axial light beam **2***w* and an off axis light beam **3***w* at a maximum angle of view at the wide angle end, an axial light beam **2***m* and an off axis light beam **3***m* at a maximum angle of view in the state in which the variable magnification optical system is in an intermediate focal point distance, and an axial light beam **2***t* and an off axis light beam **3***t* at a maximum angle of view at the telephoto end. The basic configurations of the examples illustrated in FIG. **1** through FIG. **7** as well as the manners in which the drawings are illustrated are the same. Therefore, a description will mainly be given hereinbelow with reference to the example illustrated in FIG. **1**.

This variable magnification optical system is constituted by, from the object side to the image side along an optical axis Z, a first lens group G**1** having a positive refractive power, a second lens group G**2** having a negative refractive power, and a rearward lens group GR that includes at least one lens group that moves when changing magnification and has a positive refractive power throughout the entire variable magnification range. When changing magnification from the wide angle end to the telephoto end, the first lens group G**1** is fixed with respect to an image formation plane Sim, the second lens group G**2** moves from the object side to the image side, and the distance between the rearward lens group GR and the second lens group G**2** changes. By adopting this configuration, the second lens group G**2** can bear the principal function of changing magnification. In addition, this configuration is advantageous from the viewpoint of increasing the magnification ratio.

FIG. **1** illustrates an example in which the rearward lens group GR is constituted by, in order from the object side to the image side, three lens groups, which are a third lens group G**3**, a fourth lens group G**4**, and a fifth lens group G**5**. In the example of FIG. **1**, when changing magnification from the wide angle end to the telephoto end, the third lens group G**3** and the fifth lens group G**5** are fixed with respect to the image formation plane Sim, and the fourth lens group G**4** moves from the object side to the image side, then moves from the image side to the object side thereafter. In FIG. **1**, the trajectories of movement of the second lens group G**2** and the fourth lens group G**4** are schematically indicated by the arrows beneath these lens groups.

Note that the example illustrated in FIG. **1** is that in which an aperture stop St is provided between the third lens group G**3** and the fourth lens group G**4**. However, it is possible for the aperture stop St to be provided at a position different from that of this example. Note that the aperture stop St illustrated in FIG. **1** does not necessarily represent the size or shape thereof, but indicates the position thereof along the optical axis Z. It is preferable for the aperture stop St to be fixed with respect to an image formation plane Sim when changing magnification. Adopting such a configuration is advantageous from the viewpoint of suppressing increases in the diameters of the lenses within the first lens group G**1** at the wide angle end. It is preferable for the aperture stop St to be provided between the surface most toward the image side within the second lens group G**2** and the surface most toward the object side within the lens group most toward the image side in the rearward lens group GR. Adopting such a configuration is more advantageous from the viewpoint of suppressing increases in the diameters of the lenses within the first lens group G**1** at the wide angle end. In the case that the rearward lens group GR is constituted by three lens groups, which are, in order from the object side to the image side, the third lens group G3, the fourth lens group G4, and the fifth lens group G5, it is preferable for the aperture stop St to be positioned between the surface most toward the image side within the second lens group G2 and the surface most toward the object side within the fourth lens group G4, in order to achieve a configuration which is more advantageous from the viewpoint of suppressing increases in the diameters of the lenses within the first lens group G1 at the wide angle end.

In addition, FIG. **1** illustrates an example in which a plane parallel plate shaped optical member PP is provided between the lens system and the image formation plane Sim. The optical member PP presumes the presence of various filters such as an infrared cutoff filter and a low pass filter, a cover glass, etc. In the present disclosure, the optical member PP may be provided at a position different from that in the example of FIG. **1**. In addition, a configuration from which the optical member PP is omitted is also possible.

The first lens group G1 is constituted by, in order from the object side to the image side: a first lens group front group G1A having a positive refractive power; a first lens group middle group G1B having a positive refractive power; and a first lens group rear group G1C having a negative refractive power. In the example illustrated in FIG. **1**, the first lens group front group G1A is constituted by, in order from the object side to the image side, a lens L11 and a lens L12, the first lens group middle group G1B is constituted by, in order from the object side to the image side, a lens L13 and a lens L14, and the first lens group rear group G1C is constituted by a lens L15.

The first lens group front group G1A is constituted by a cemented lens formed by cementing a negative lens and a positive lens, provided in this order from the object side to the image side, together, which has a positive refractive power as a whole. The first lens group middle group G1B is constituted by a cemented lens formed by cementing a negative lens and a positive lens, provided in this order from the object side to the image side, together, which has a positive refractive power as a whole. Providing two cemented lenses having positive refractive powers consecutively from the most object side in this manner is advantageous from the viewpoints of reducing the amounts of spherical aberration and longitudinal chromatic aberration at the telephoto side.

The cemented lens of the first lens group front group G1A is configured such that the coupling surface thereof is convex toward the object side. Thereby, differences in spherical aberration curves depending on wavelengths and the generation of higher order spherical aberration can be suppressed. The cemented lens of the first lens group front group G1A is configured such that the surface most toward the object side within the first lens group front group G1A is convex. Adopting such a configuration is advantageous from the viewpoint of shortening the total length of the variable magnification optical system. The cemented lens of the first lens group middle group G1B is configured such that the coupling surface of the cemented lens of the first lens group middle group G1B is convex toward the object side. Thereby, differences in spherical aberration curves depending on wavelengths and the generation of higher order spherical aberration can be suppressed. The surface most toward the object side within the first lens group middle group G1B is configured to be convex. Adopting such a configuration is advantageous from the viewpoints of shortening the total length of the variable magnification optical system and reducing the amount of spherical aberration.

The first lens group rear group G1C consists of one negative lens. Adopting such a configuration is advantageous from the viewpoints of correcting spherical aberration at the telephoto end and correcting distortion at the wide angle end. As illustrated in FIG. **8**, the axial light beam **2*w*** at the negative lens most toward the image side within the first lens group G1 is narrow at the wide angle end. The height of marginal light rays thereof is not high, but the height of the marginal light ray of the axial light beam **2*t*** at the negative lens is high at the telephoto end. By the first lens group G1 being of the configuration described above and providing a negative lens at the most image side of the first lens group G1, this negative lens can favorably correct spherical aberration at the telephoto end without influencing spherical aberration at the wide angle end to a great degree.

Further, this variable magnification optical system is configured such that Conditional Formula (1) below related to the second lens group G2, which bears the principal magnification changing function, is satisfied.

$$-50<fT/f2<-10 \quad (1)$$

wherein fT is the focal length of the entire optical system at the telephoto end, and f2 is the focal length of the second lens group.

By configuring the variable magnification optical system such that the value of fT/f2 is not less than or equal to the lower limit defined in Conditional Formula (1), fluctuations in various aberrations when changing magnification, particularly spherical aberration and distortion, can be suppressed. Configuring the variable magnification optical system such that the value of fT/f2 is not greater than or equal to the upper limit defined in Conditional Formula (1) is advantageous from the viewpoints of increasing the magnification ratio and shortening the total length of the variable magnification optical system.

It is preferable for Conditional Formula (1-1) below to be satisfied, in order to cause the advantageous effects related to the lower limit of Conditional Formula (1) to become more prominent, while obtaining the advantageous effects related to the upper limit of Conditional Formula (1).

$$-40<fT/f2<-10 \quad (1\text{-}1)$$

In addition, it is preferable for Conditional Formula (1-2) below to be satisfied, in order to cause the advantageous effects related to Conditional Formula (1) to become more prominent.

$$-40<fT/f2<-15 \quad (1\text{-}2)$$

In addition, it is preferable for Conditional Formula (2) below to be satisfied in this variable magnification optical system.

$$2<fT/f1<5 \quad (2)$$

wherein fT is the focal length of the entire optical system at the telephoto end, and f1 is the focal length of the first lens group.

Configuring the variable magnification optical system such that the value of fT/f1 is not less than or equal to the lower limit defined in Conditional Formula (2) is advantageous from the viewpoint of shortening the total length of the variable magnification optical system. Configuring the variable magnification optical system such that the value of fT/f1 is not greater than or equal to the upper limit defined in Conditional Formula (2) is advantageous from the viewpoints of increasing the magnification ratio and reducing the amount of spherical aberration at the telephoto end. It is preferable for Conditional Formula (2-1) below to be satisfied, in order to cause the advantageous effects related to Conditional Formula (2) to become more prominent.

$$2.5<fT/f1<3.5 \qquad (2\text{-}1)$$

In addition, it is preferable for Conditional Formula (3) below to be satisfied in this variable magnification optical system.

$$-1.5<f1/f1C<-0.3 \qquad (3)$$

wherein f1 in the focal length of the first lens group, and f1C is the focal length of the first lens group rear group.

By setting the value of f1/f1C to be within the range defined in Conditional Formula (3), correcting spherical aberration to an appropriate range will be facilitated. It is more preferable for Conditional Formula (3-1) below to be satisfied, in order to cause the advantageous effect related to Conditional Formula (3) to become more prominent.

$$-1<f1/f1C<-0.5 \qquad (3\text{-}1)$$

In addition, it is preferable for Conditional Formula (4) below to be satisfied in this variable magnification optical system.

$$0<(L1Cf+L1Cr)/(L1Cf-L1Cr)<0.95 \qquad (4)$$

wherein L1Cf is the radius of curvature of the surface toward the object side of the negative lens of the first lens group rear group, and L1Cr is the radius of curvature of the surface toward the image side of the negative lens of the first lens group rear group.

As described previously, the negative lens of the first lens group rear group G1C is important in correcting spherical aberration at the telephoto end. Conditional Formula (4) is a formula related to the shape of this negative lens. By maintaining the value of (L1Cf+L1Cr)/(L1Cf−L1Cr) to be within the range defined in Conditional Formula (4), spherical aberration at the telephoto end can be favorably corrected. It is more preferable for Conditional Formula (4-1) below to be satisfied, in order to cause the advantageous effect related to Conditional Formula (4) to become more prominent.

$$0.05<(L1Cf+L1Cr)/(L1Cf-L1Cr)<0.5 \qquad (4\text{-}1)$$

In addition, it is preferable for Conditional Formulae (5) and (6) below related to the positive lens and the negative lens that constitute the cemented lens of the first lens group front group G1A to be satisfied.

$$0<\nu Ap-\nu An<35 \qquad (5)$$

$$60<(\nu Ap+\nu An)/2<90 \qquad (6)$$

wherein νAp is the Abbe's number with respect to the d line of the positive lens within the first lens group front group, and νAn is the Abbe's number with respect to the d line of the negative lens within the first lens group front group.

By configuring the variable magnification optical system such that the value of νAp−νAn is not less than or equal to the lower limit defined in Conditional Formula (5), favorable correction of longitudinal chromatic aberration at the telephoto end will be facilitated. By configuring the variable magnification optical system such that the value of νAp−νAn is not greater than or equal to the upper limit defined in Conditional Formula (5), the generation of second order longitudinal chromatic aberration at the telephoto end can be suppressed. It is more preferable for Conditional Formula (5-1) below, in order to cause the advantageous effects related to Conditional Formula (5) to become more prominent.

$$5<\nu Ap-\nu An<30 \qquad (5\text{-}1)$$

By configuring the variable magnification optical system such that the value of (νAp+νAn)/2 is not less than or equal to the lower limit defined in Conditional Formula (6), the generation of second order longitudinal chromatic aberration at the telephoto end can be suppressed. By selecting materials from among currently utilizable optical materials such that the value of (νAp+νAn)/2 is not greater than or equal to the upper limit defined in Conditional Formula (6), materials having a difference in refractive indices can be selected for the positive lens and the negative lens that constitute the cemented lens of the first lens group front group G1A, which is advantageous from the viewpoint of correcting spherical aberration. It is more preferable for Conditional Formula (6-1) below, in order to cause the advantageous effects related to Conditional Formula (6) to become more prominent.

$$65<(\nu Ap+\nu An)/2<80 \qquad (6\text{-}1)$$

Note that it is possible to arbitrarily set the number of lens groups that constitute the rearward lens group GR. Two lens groups may constitute the rearward lens group GR, or three lens groups may constitute the rearward lens group GR. For example, the rearward lens group GR may be constituted by, in order from the object side to the image side, a third lens group G3 having a positive refractive power which is fixed with respect to the image formation plane Sim when changing magnification, a fourth lens group G4 having a negative refractive power that moves when changing magnification, and a fifth lens group G5 having a positive refractive power, the distance between the fourth lens group G4 and the fifth lens group G5 changing when changing magnification.

In the case that the rearward lens group GR is constituted by the three lens groups described above, increases in the diameters of the lenses within the fourth lens group G4 and the fifth lens group G5 can be suppressed by the third lens group G3 having a positive refractive power. In addition, the third lens group G3 having a positive refractive power also exhibits the effect of decreasing spherical aberration. The amount of movement of the fourth lens group G4 can be suppressed by the fourth lens group G4 having a negative refractive power, which contributes to a shortening of the total length of the variable magnification optical system. In addition, fluctuations in an image formation position, which are caused by the second lens group G2 moving when changing magnification, can be corrected by the fourth lens group G4 moving when changing magnification. The incident angles of principal light rays at peripheral angles of view that enter the image formation plane Sim can be suppressed, by the fifth lens group G5 having a positive refractive power. Note that it is preferable for the fifth lens group G5 to be fixed with respect to the image formation plane Sim when changing magnification. In this case, preventing entry of dust into the interior of the optical system can be facilitated. In addition, by configuring the variable magnification optical system such that only the second lens group G2 and the fourth lens group G4 move when changing magnification, the mechanism of an imaging apparatus can be simplified compared to a case in which the second lens group G2, the fourth lens group G4, and the fifth lens group G5 move. Adopting this configuration contributes to an improvement in the reliability of the imaging apparatus.

In the case that the rearward lens group GR is constituted by the three lens groups described above, it is preferable for Conditional Formula (7) below to be satisfied.

$$-1\beta 5T<0 \qquad (7)$$

wherein β5T is the transverse magnification ratio of the fifth lens group in a state focused on an object at infinity at the telephoto end.

That the transverse magnification ratio of the fifth lens group G5 is negative means that divergent light enters the fifth lens group G5 and exits as convergent light. By configuring the variable magnification optical system such that the value of β5T is not less than or equal to the lower limit defined in Conditional Formula (7), the refractive power of the fifth lens group G5 can be prevented from becoming excessively strong, and it will become possible to reduce the amount of spherical aberration. By configuring the variable magnification optical system such that the value of β5T is not greater than or equal to the upper limit defined in Conditional Formula (7), the amount of movement of the fourth lens group G4 when changing magnification can be suppressed, which contributes to a shortening of the total length of the variable magnification optical system. It is more preferable for Conditional Formula (7-1) below to be satisfied, in order to cause the advantageous effects related to Conditional Formula (7) to become more prominent.

$$-0.6<\beta 5T<-0.2 \quad (7\text{-}1)$$

In addition, in the case that the rearward lens group GR is constituted by the three lens groups described above, it is preferable for Conditional Formula (8) below to be satisfied.

$$1.15<\beta 4T/\beta 4W<3 \quad (8)$$

wherein β4T is the transverse magnification ratio of the fourth lens group in a state focused on an object at infinity at the telephoto end, and β4W is the transverse magnification ratio of the fourth lens group in a state focused on an object at infinity at the wide angle end.

By configuring the variable magnification optical system such that the value of β4T/β4W is not less than or equal to the lower limit defined in Conditional Formula (8), the function of changing magnification can be favorably distributed between the second lens group G2 and the fourth lens group G4, which is advantageous from the viewpoint of increasing the magnification ratio of the variable magnification optical system. By configuring the variable magnification optical system such that the value of β4T/β4W is not greater than or equal to the upper limit defined in Conditional Formula (8), the amount of movement of the fourth lens group G4 when changing magnification can be suppressed, which contributes to a shortening of the total length of the variable magnification optical system. Note that in the case that Conditional Formula (8) is satisfied and the variable magnification optical system is configured such that the fourth lens group moves during focusing operations, the amount of movement of the fourth lens group G4 during focusing operations can be suppressed. It is more preferable for Conditional Formula (8-1) below to be satisfied, in order to cause the advantageous effects related to Conditional Formula (8) to become more prominent.

$$1.2<\beta 4T/\beta 4W<2 \quad (8\text{-}1)$$

In the case that the rearward lens group GR is constituted by the three lens groups described above, any of the third lens group G3, the fourth lens group G4, and the fifth lens group G5 may be employed as the lens group that moves during focusing operations (hereinafter, also referred to as "focusing group"). Further, only a portion of these lens groups may be the focusing group.

For example, only a portion of the third lens group G3 may be the focusing group. In this case, it is preferable for the third lens group G3 to be constituted by, in order from the object side to the image side: a third lens group front group G3A having a positive refractive power and a third lens group rear group G3B having a positive refractive power, for the variable magnification optical system to be configured such that only the third lens group front group G3A moves during focusing operations, and for the third lens group front group G3A to move from the object side to the image side when changing focus from that on an object at infinity to that to an object at a proximal distance. The example illustrated in FIG. 1 adopts this configuration, and an arrow that indicates the direction of movement of the third lens group front group G3A, which is the focusing group, when changing focus from that on an object at infinity to that to an object at a proximal distance is illustrated in FIG. 1 with the text "focus". In the case that such a configuration is adopted, a converging effect can be administered by the third lens group front group G3A onto divergent light that propagates from the second lens group G2 toward the third lens group G3, by the third lens group G3 being divided into two positive lens groups. As a result, light output from the third lens group front group G3A can approximate collimated light. In the case that the light output from the third lens group front group G3A is collimated light, focusing operations can be performed without changing the image forming relationship of the third lens group front group G3A, by moving the third lens group front group G3A along the optical axis for a distance corresponding to an amount of displacement of a pseudo image position of the divergent light caused by changes in an object distance. Accordingly, fluctuations in the angle of view during focusing operations can be decreased in the case that the light output from the third lens group front group G3A is collimated light or approximates collimated light.

Alternatively, the fourth lens group G4 may be the focusing group. In this case, it is preferable for the variable magnification optical system is configured such that the transverse magnification ratio of the fourth lens group G4 in a state focused on an object at infinity to be negative throughout the entire variable magnification range, for only the fourth lens group G4 to move during focusing operations, and for the fourth lens group G4 to move from the object side toward the image side when changing focus from that on an object at infinity to that on an object at a proximal distance. The fourth lens group G4 is a negative lens group. That the transverse magnification ratio of a negative lens group is negative means that convergent light that enters this negative lens group is output as divergent light. Therefore, the focusing group can be miniaturized in the case that the fourth lens group G4 is the focusing group.

As a further alternative, only a portion of the fifth lens group G5 may be the focusing group. In this case, it is preferable for the fifth lens group G5 to consist of, in order from the object side to the image side: a fifth lens group front group G5A having a positive refractive power, a fifth lens group middle group G5B having a positive refractive power, and a fifth lens group rear group G5C having a negative refractive power, and for the variable magnification optical system to be configured such that only the fifth lens group middle group G5B moves during focusing operations, and the fifth lens group middle group G5B moves from the image side to the object side when changing focus from that on an object at infinity to that to an object at a proximal distance. In the case that this configuration is adopted, light beams can be converged by the fifth lens group front group G5A. Therefore, the focusing group can be miniaturized.

Arbitrary combinations of the preferred configurations and the possible configurations described above, including the conditional formulae, are possible. It is preferable for the configurations to be selectively adopted as appropriate, according to specifications required of the variable magnification optical system. According to the present embodiment, it is possible to realize a variable magnification optical system having a high variable magnification ratio and high optical performance. Note that here, a "high variable magnification ratio" refers to a magnification ratio of 30× or greater.

Next, examples of numerical values of the variable magnification optical system of the present disclosure will be described.

Example 1

The lens configuration of the variable magnification optical system of Example 1 is illustrated in FIG. **1** and FIG. **8**. The manner in which the variable magnification optical system is illustrated has been described above, and therefore, redundant descriptions will be omitted here. The variable magnification optical system of Example 1 has a group configuration constituted by, in order from the object side to the image side, the first lens group G**1** having a positive refractive power, the second lens group G**2** having a negative refractive power, the third lens group G**3** having a positive refractive power, the aperture stop St, the fourth lens group G**4** having a negative refractive power, and the fifth lens group G**5** having a positive refractive power. Among these lens groups, the third lens group G**3** through the fifth lens group G**5** constitute the rearward lens group GR. The rearward lens group GR has a positive refractive power throughout the entire variable magnification range. When changing magnification from the wide angle end to the telephoto end, the first lens group G**1**, the third lens group G**3**, the aperture stop St, and the fifth lens group G**5** are fixed with respect to the image formation plane Sim, while the second lens group G**2** moves form the object side to the image side, and the fourth lens group G**4** moves from the object side to the image side, then from the image side to the object side.

Only a portion of the third lens group G**3** moves during focusing operations. In the variable magnification optical system of Example 1, the third lens group G**3** is constituted by, in order from the object side to the image side, the third lens group front group G**3**A having a positive refractive power, and the third lens group rear group G**3**B having a positive refractive power. When changing focus from that on an object at infinity to that on an object at a proximal distance, the third lens group front group G**3**A moves from the object side to the image side, while the third lens group rear group G**3**B is fixed with respect to the image formation plane Sim.

The first lens group G**1** is constituted by, in order from the object side to the image side, lenses L**11** through L**15**, and the second lens group G**2** is constituted by, in order from the object side to the image side, lenses L**21** through L**25**. The third lens group front group G**3**A is constituted by a positive lens L**31**, and the third lens group rear group G**3**B is constituted by, in order from the object side to the image side, lenses L**32** and L**33**. The fourth lens group G**4** is constituted by, in order from the object side to the image side, lenses L**41** and L**42**, and the fifth lens group G**5** is constituted by, in order from the object side to the image side, lenses L**51** through L**59**.

Basic lens data of Example 1 are shown in Table 1, and items and variable distances among surfaces of Example 1 are shown in Table 2. In Table 1, ith (i=1, 2, 3, . . .) surface numbers that sequentially increase from the object side to the image side, with the surface toward the object side of the constituent element at the most object side designated as first, are shown in the column Si. The radii of curvature of ith surfaces are shown in the column Ri. The distances along the optical axis Z between an ith surface and an i+1st surface are shown in the column Di. The refractive indices with respect to the d line (wavelength: 587.6 nm) of jth (j=1, 2, 3, . . .) constituent elements that sequentially increase from the object side to the image side, with the constituent element at the most object side designated as first, are shown in the column Ndj. The Abbe's numbers of jth constituent elements with respect to the d line are shown in the column νdj.

Here, the signs of the radii of curvature are positive for surface shapes which are convex toward the object side, and negative for surface shapes which are convex toward the image side. Table 1 also shows the aperture stop St and the optical member PP. In Table 1, a surface number and text reading "(St)" are shown in the row of the surface number of the surface corresponding to the aperture stop St. The value in the lowermost row of Di is the distance between the surface most toward the image side of the variable magnification optical system and the image formation plane Sim. In addition, in Table 1, variable distances are indicated by DD [ ]. The surface number toward the object side is shown in the brackets [ ], and written in the column Di. Note that the values shown in Table 1 are those in a state in which the variable magnification optical system is focused on an object at infinity.

The zoom ratio Zr, the focal length f of the entire variable magnification optical system, the F number F No., the full angle of view **2***w*, and the values of variable distances with the d line as a reference are shown in Table 2. The indication)"(°)" in the row **2***w* means that the units are degrees. In Table 2, the above values for the wide angle end, an intermediate focal point distance state, and the telephoto end are respectively shown in the columns "Wide Angle", "Intermediate", and "Telephoto". The data of Table 1 and the values of the variable distances in Table 2 are those in a state in which the variable magnification optical system is focused on an object at infinity.

In the data of the tables, degrees are employed as units for angles, and mm are employed as units for lengths. However, optical systems may be enlarged proportionately or reduced proportionately and utilized. Therefore, other appropriate units may be employed. In addition, the numerical values shown in each of the tables below are those which are rounded off at a predetermined number of digits.

TABLE 1

Example 1

Si	Ri	Di	Ndj	νdj
1	83.64030	2.193	1.54341	64.11
2	53.14260	17.928	1.49700	81.54
3	−784.39213	0.243		
4	83.21753	2.024	1.83827	42.96
5	51.29111	12.031	1.49700	81.54
6	3247.30104	2.340		
7	−360.86227	2.601	1.58913	61.13
8	276.94512	DD [8]		
9	−245.08935	1.000	1.70970	56.02
10	54.43469	2.615		
11	−108.08718	1.000	1.71299	53.87
12	62.57532	1.056		
13	28.43116	3.389	1.95001	17.50

TABLE 1-continued

Example 1				
Si	Ri	Di	Ndj	νdj
14	63.39468	2.599	1.79507	48.49
15	27.10153	3.759		
16	−74.55103	0.800	1.74035	53.96
17	96.67023	DD [17]		
18	289.49075	2.818	1.78003	50.00
19	−62.24178	9.153		
20	56.50669	3.831	1.72888	55.06
21	−32.96701	0.823	1.89959	23.21
22	−104.74184	3.000		
23 (St)	∞	DD [23]		
24	−44.75934	0.810	1.88500	39.50
25	14.74807	2.350	2.00001	26.03
26	42.94455	DD [26]		
27	23.75891	4.056	1.49700	81.54
28	−85.90010	0.263		
29	40.89615	1.200	1.79905	47.58
30	15.85152	5.348	1.52737	75.11
31	−34.02029	0.166		
32	−29.26989	0.800	1.80000	48.00
33	27.30973	3.410	1.58644	66.70
34	−58.65900	0.100		
35	46.43391	3.770	1.62474	58.25
36	−28.14008	0.800	1.80001	48.00
37	−93.70162	10.000		
38	−75.95737	0.800	1.79998	48.00
39	9.89884	3.996	1.72738	28.63
40	2785.29076	5.000		
41	∞	4.000	1.51633	64.14
42	∞	12.176		

TABLE 2

Example 1			
	Wide Angle	Intermediate	Telephoto
Zr	1.0	5.0	36.3
F	13.434	67.129	486.399
F No.	2.48	4.04	7.02
2ω (°)	49.0	9.8	1.4
DD [8]	3.757	51.827	85.224
DD [17]	84.430	36.360	2.963
DD [23]	3.000	20.702	47.624
DD [26]	46.277	28.575	1.653

FIG. **9** is a collection of aberration diagrams of the variable magnification optical system of Example 1 in a state focused on an object at infinity. The aberration diagrams of FIG. **9** illustrate spherical aberration, the astigmatic aberration, the distortion, and the lateral chromatic aberration (chromatic aberration of magnification) in order from the left side of the drawing sheet. Aberrations at the wide angle end are illustrated in the upper portion of FIG. **9** labeled WIDE, aberrations at the intermediate focal point distance state are illustrated in the middle portion of FIG. **9** labeled MIDDLE, and aberrations at the telephoto end are illustrated in the lower portion of FIG. **9** labeled TELE. In the diagrams that illustrate spherical aberration, aberrations related to the d line (wavelength: 587.6 nm), the C line (wavelength: 656.3 nm), the F line (wavelength: 486.1 nm), and the g line (wavelength: 435.8 nm) are indicated by a black solid line, a long broken line, a short broken line, and a gray solid line, respectively. In the diagrams that illustrate astigmatism, aberrations related to the d line in the sagittal direction and the tangential direction are indicated by a solid line and a short broken line, respectively. In the diagrams that illustrate distortion, aberrations related to the d line are indicated by solid lines. In the diagrams that illustrate lateral chromatic aberration, aberrations related to the C line, the F line, and the g line are indicated by a long broken line, a short broken line, and a gray solid line, respectively. In the diagrams that illustrate spherical aberration, "FNo." denotes F numbers, and in the diagrams that illustrate other aberrations, "w" denotes half angles of view.

The symbols, the meanings, and the manner in which the data are shown in the description of Example 1 above are the same for the following Examples to be described later, unless particularly noted. Therefore, redundant descriptions thereof will be omitted below.

Example 2

The lens configuration of the variable magnification optical system according to Example 2 is illustrated in FIG. **2**. The configuration of lens groups, the lens groups that move when changing magnification, and the directions of movement thereof in the variable magnification optical system of Example 2 are the same as those of the variable magnification optical system of Example 1.

Only a portion of a third lens group G**3** moves during focusing operations. In the variable magnification optical system of Example 2, the third lens group G**3** is constituted by, in order from the object side to the image side, a third lens group front group G**3**A having a positive refractive power, and a third lens group rear group G**3**B having a positive refractive power. When changing focus from that on an object at infinity to that on an object at a proximal distance, the third lens group front group G**3**A moves from the object side to the image side, while the third lens group rear group G**3**B is fixed with respect to the image formation plane Sim.

A first lens group G**1** is constituted by, in order from the object side to the image side, lenses L**11** through L**15**, and a second lens group G**2** is constituted by, in order from the object side to the image side, lenses L**21** through L**25**. The third lens group front group G**3**A is constituted by a cemented lens formed by cementing a positive lens L**31** and a negative lens L**32** together, and the third lens group rear group G**3**B is constituted by, in order from the object side to the image side, lenses L**33** and L**34**. A fourth lens group G**4** is constituted by, in order from the object side to the image side, lenses L**41** and L**42**, and a fifth lens group G**5** is constituted by, in order from the object side to the image side, lenses L**51** through L**59**.

Basic lens data are shown in Table 3, various items and variable distances are shown in Table 4, and aberration diagrams for a state focused on an object at infinity are illustrated in FIG. **10** for the variable magnification optical system of Example 2.

TABLE 3

Example 2				
Si	Ri	Di	Ndj	νdj
1	83.63107	2.156	1.54224	64.67
2	52.93354	17.005	1.49700	81.54
3	−758.68040	0.100		
4	83.76092	2.000	1.83892	43.42
5	51.74014	11.219	1.49700	81.54
6	4941.56580	2.056		
7	−359.85288	2.892	1.58913	61.13
8	282.28376	DD [8]		
9	−244.28151	1.000	1.70359	56.32
10	53.86953	3.091		
11	−105.93134	1.000	1.71299	53.87

TABLE 3-continued

Example 2				
Si	Ri	Di	Ndj	νdj
12	63.01961	1.000		
13	28.55991	4.155	1.93584	18.30
14	68.64705	0.810	1.76795	51.21
15	27.38442	4.593		
16	−72.74801	0.800	1.70674	49.80
17	97.00714	DD [17]		
18	120.27933	4.011	1.59349	67.00
19	−33.13104	1.162	1.58278	59.00
20	−55.91667	9.215		
21	57.16094	3.653	1.71985	55.51
22	−30.61215	0.800	1.89828	27.70
23	−103.79744	3.000		
24 (St)	∞	DD [24]		
25	−44.34142	0.810	1.87236	40.76
26	14.53073	2.588	1.97664	26.20
27	43.39989	DD [27]		
28	23.61535	4.623	1.49700	81.54
29	−82.40960	0.263		
30	40.09191	1.200	1.79333	48.67
31	15.95913	5.537	1.52580	63.89
32	−34.32984	0.193		
33	−29.15246	0.800	1.79915	39.90
34	28.11087	2.966	1.58257	65.15
35	−60.94183	0.100		
36	43.75330	3.648	1.61488	56.94
37	−26.64577	0.800	1.77990	50.01
38	−101.92430	10.000		
39	−61.37342	0.800	1.78654	49.35
40	9.27079	3.291	1.72979	29.84
41	6403.39586	5.000		
42	∞	4.000	1.51633	64.14
43	∞	11.988		

TABLE 4

Example 2			
	Wide Angle	Intermediate	Telephoto
Zr	1.0	5.0	36.3
F	13.243	66.182	479.080
F No.	2.53	4.11	7.07
2ω (°)	50.0	9.8	1.4
DD [8]	3.615	51.808	85.808
DD [17]	83.814	35.621	1.621
DD [24]	3.000	21.175	47.332
DD [27]	46.885	28.710	2.553

Example 3

The lens configuration of the variable magnification optical system according to Example 3 is illustrated in FIG. **3**. The configuration of lens groups, the lens groups that move when changing magnification, and the directions of movement thereof in the variable magnification optical system of Example 3 are the same as those of the variable magnification optical system of Example 1.

Only a portion of a third lens group G**3** moves during focusing operations. In the variable magnification optical system of Example 3, the third lens group G**3** is constituted by, in order from the object side to the image side, a third lens group front group G**3**A having a positive refractive power, and a third lens group rear group G**3**B having a positive refractive power. When changing focus from that on an object at infinity to that on an object at a proximal distance, the third lens group front group G**3**A moves from the object side to the image side, while the third lens group rear group G**3**B is fixed with respect to the image formation plane Sim.

A first lens group G**1** is constituted by, in order from the object side to the image side, lenses L**11** through L**15**, and a second lens group G**2** is constituted by, in order from the object side to the image side, lenses L**21** through L**25**. The third lens group front group G**3**A is constituted by a positive lens L**31** which is a single lens and a negative lens L**32** which is a single lens, and the third lens group rear group G**3**B is constituted by, in order from the object side to the image side, lenses L**33** and L**34**. A fourth lens group G**4** is constituted by, in order from the object side to the image side, lenses L**41** and L**42**, and a fifth lens group G**5** is constituted by, in order from the object side to the image side, lenses L**51** through L**59**.

Basic lens data are shown in Table 5, various items and variable distances are shown in Table 6, and aberration diagrams for a state focused on an object at infinity are illustrated in FIG. **11** for the variable magnification optical system of Example 3.

TABLE 5

Example 3				
Si	Ri	Di	Ndj	νdj
1	90.87887	2.418	1.50001	73.91
2	52.93674	15.832	1.49700	81.54
3	1078.00597	0.954		
4	79.44116	2.014	1.83714	39.36
5	48.49353	11.785	1.49700	81.54
6	6074.67193	0.758		
7	−5801.13160	2.000	1.49700	81.54
8	242.11765	DD [8]		
9	−171.05762	1.691	1.73004	55.00
10	62.64558	2.341		
11	−94.51213	1.000	1.71299	53.87
12	72.01444	1.000		
13	27.44271	5.039	1.95001	18.37
14	64.88904	1.241	1.79019	41.51
15	25.99552	3.998		
16	−86.19512	0.800	1.70936	55.60
17	81.96521	DD [17]		
18	167.01058	2.982	1.80001	48.00
19	−52.94757	0.100		
20	−52.94757	0.823	1.79719	41.34
21	−72.93886	8.838		
22	61.83946	2.010	1.71770	55.62
23	−32.38593	1.356	1.89498	23.97
24	−102.93667	3.000		
25 (St)	∞	DD [25]		
26	−50.18296	0.810	1.87658	40.15
27	15.09080	1.655	2.00001	25.62
28	40.29609	DD [28]		
29	23.63938	5.380	1.49700	81.54
30	−110.61381	0.270		
31	34.41765	1.215	1.79529	48.23
32	16.48881	6.877	1.51387	71.96
33	−33.44173	0.284		
34	−29.37505	0.800	1.79653	47.52
35	22.49067	3.393	1.53837	74.10
36	−74.14385	0.100		
37	41.49434	4.178	1.62020	60.65
38	−26.18224	0.800	1.79731	48.27
39	−102.43969	10.000		
40	−140.73949	0.800	1.79918	48.08
41	9.65709	3.332	1.72260	28.87
42	897.46882	5.000		
43	∞	4.000	1.51633	64.14
44	∞	12.130		

TABLE 6

Example 3			
	Wide Angle	Intermediate	Telephoto
Zr	1.0	5.0	36.3
F	13.160	65.756	476.753
F No.	2.45	4.08	7.13
2ω (°)	52.0	10.0	1.4
DD [8]	3.587	51.335	85.677
DD [17]	84.552	36.804	2.462
DD [25]	3.000	21.715	48.091
DD [28]	47.758	29.043	2.667

Example 4

The lens configuration of the variable magnification optical system according to Example 4 is illustrated in FIG. **4**. The configuration of lens groups, the lens groups that move when changing magnification, and the directions of movement thereof in the variable magnification optical system of Example 4 are the same as those of the variable magnification optical system of Example 1.

Only a fourth lens group G**4** moves during focusing operations. When changing focus from that on an object at infinity to that on an object at a proximal distance, the fourth lens group G**4** moves from the object side to the image side. The variable magnification optical system of Example 4 is configured such that the transverse magnification ratio of the fourth lens group G**4** in a state focused on an object at infinity is negative throughout the entire variable magnification range.

A first lens group G**1** is constituted by, in order from the object side to the image side, lenses L**11** through L**15**, a second lens group G**2** is constituted by, in order from the object side to the image side, lenses L**21** through L**25**, and a third lens group G**3** is constituted by, in order from the object side to the image side, lenses L**31** through L**35**. The fourth lens group G**4** is constituted by, in order from the object side to the image side, a negative lens L**41**, which is a single lens, and a cemented lens formed by cementing a positive lens L**42** and a negative lens L**43** together. A fifth lens group G**5** is constituted by, in order from the object side to the image side, lenses L**51** through L**58**. Note that in the example illustrated in FIG. **4**, plane parallel plate shaped optical members PP**1** and PP**2** are respectively provided between the lens L**56** and the lens L**57**, and between the fifth lens group G**5** and an image formation plane Sim. The optical members PP**1** and PP**2** are similar to the optical member PP illustrated in FIG. **1**, and are not essential components of the present disclosure. The optical member PP**1** may be a wavelength switching filter to be employed when switching wavelengths to be utilized from the visible range to the infrared range, for example.

Basic lens data are shown in Table 7, various items and variable distances are shown in Table 8, and aberration diagrams for a state focused on an object at infinity are illustrated in FIG. **12** for the variable magnification optical system of Example 4.

TABLE 7

Example 4				
Si	Ri	Di	Ndj	νdj
1	77.54033	2.010	1.58821	60.73
2	52.42394	14.955	1.49700	81.54
3	−633.69949	0.100		

TABLE 7-continued

Example 4				
Si	Ri	Di	Ndj	νdj
4	75.38537	2.000	1.70001	49.65
5	42.79620	14.692	1.49700	81.54
6	−314.78656	1.082		
7	−268.03251	2.000	1.68652	57.17
8	184.93173	DD [8]		
9	−235.72782	1.000	1.79999	48.00
10	45.45757	2.943		
11	−64.70170	1.000	1.80001	48.00
12	61.71493	0.200		
13	44.96674	6.265	1.77505	26.25
14	−29.26227	0.810	1.54582	65.94
15	80.30118	1.931		
16	−50.61195	0.811	1.80000	48.00
17	94.36966	DD [17]		
18	135.76183	5.903	1.56769	55.95
19	−16.01208	1.000	1.90001	36.00
20	−52.86444	4.295		
21	1075.10458	4.798	1.68378	44.48
22	−27.45210	0.100		
23	61.06515	5.032	1.60626	63.65
24	−28.12944	0.800	1.90001	36.32
25	−184.18910	3.000		
26 (St)	∞	DD [26]		
27	−66.44183	1.624	1.90000	35.14
28	56.87833	0.829		
29	−53.61995	3.771	1.78799	25.60
30	−13.96524	0.810	1.68592	57.20
31	115.84133	DD [31]		
32	25.74427	6.070	1.49700	81.54
33	−127.27458	0.100		
34	32.48971	1.000	1.80001	46.82
35	15.84736	8.071	1.49700	81.54
36	−34.20556	0.443		
37	−29.31621	0.946	1.75908	52.09
38	−166.97844	0.110		
39	26.21151	5.603	1.47999	58.75
40	−37.26666	2.922	1.47999	58.75
41	44.46866	3.500		
42	∞	1.000	1.51633	64.14
43	∞	3.975		
44	52.16868	2.213	1.74368	53.63
45	10.02508	6.010	1.47999	58.75
46	99.99640	5.000		
47	∞	1.000	1.51633	64.14
48	∞	14.467		

TABLE 8

Example 4			
	Wide Angle	Intermediate	Telephoto
Zr	1.0	3.8	36.3
F	11.737	45.089	424.836
F No.	2.61	3.61	6.54
2ω (°)	44.8	11.6	1.2
DD [8]	2.894	37.512	74.131
DD [17]	72.650	38.032	1.413
DD [26]	3.000	15.943	35.480
DD [31]	47.052	34.109	14.572

Example 5

The lens configuration of the variable magnification optical system according to Example 5 is illustrated in FIG. **5**. The configuration of lens groups, the lens groups that move when changing magnification, and the directions of movement thereof in the variable magnification optical system of Example 5 are the same as those of the variable magnification optical system of Example 1.

Only a fourth lens group G**4** moves during focusing operations. When changing focus from that on an object at infinity to that on an object at a proximal distance, the fourth lens group G**4** moves from the object side to the image side. The variable magnification optical system of Example 5 is configured such that the transverse magnification ratio of the fourth lens group G**4** in a state focused on an object at infinity is negative throughout the entire variable magnification range.

A first lens group G**1** is constituted by, in order from the object side to the image side, lenses L**11** through L**15**, a second lens group G**2** is constituted by, in order from the object side to the image side, lenses L**21** through L**25**, and a third lens group G**3** is constituted by, in order from the object side to the image side, lenses L**31** through L**35**. The fourth lens group G**4** is constituted by, in order from the object side to the image side, a negative lens L**41**, which is a single lens, and a cemented lens formed by cementing a positive lens L**42** and a negative lens L**43** together. A fifth lens group G**5** is constituted by, in order from the object side to the image side, lenses L**51** through L**58**. Note that in the example illustrated in FIG. **5**, plane parallel plate shaped optical members PP**1** and PP**2** are respectively provided between the lens L**54** and the lens L**55**, and between the fifth lens group G**5** and an image formation plane Sim. The optical members PP**1** and PP**2** are similar to the optical members PP**1** and PP**2** illustrated in FIG. **4**, and are not essential components of the present disclosure.

Basic lens data are shown in Table 9, various items and variable distances are shown in Table 10, and aberration diagrams for a state focused on an object at infinity are illustrated in FIG. **13** for the variable magnification optical system of Example 5.

TABLE 9

Example 5

Si	Ri	Di	Ndj	νdj
1	77.80900	2.010	1.58339	61.51
2	51.97341	13.902	1.49700	81.54
3	−562.95420	0.100		
4	74.85762	2.000	1.69209	48.97
5	42.66922	13.628	1.49700	81.54
6	−299.05772	0.691		
7	−263.66968	2.000	1.69784	55.86
8	204.66438	DD [8]		
9	−204.46844	1.000	1.80001	48.00
10	43.11333	2.722		
11	−59.60573	1.000	1.80000	48.00
12	60.88263	0.200		
13	44.58596	5.972	1.78938	25.53
14	−28.59457	0.810	1.53195	59.42
15	69.25686	1.920		
16	−48.65029	0.908	1.80000	46.48
17	95.65677	DD [17]		
18	257.81491	5.751	1.56268	56.80
19	−15.77386	1.000	1.89999	36.99
20	−52.63438	3.032		
21	1394.13910	4.689	1.68210	46.45
22	−26.77273	0.100		
23	66.14982	4.787	1.61626	62.11
24	−28.38781	0.800	1.89999	37.50
25	−160.89785	3.000		
26 (St)	∞	DD [26]		
27	−59.53123	1.159	1.82978	39.71
28	64.65986	0.882		
29	−56.65936	3.767	1.80249	26.43
30	−16.80782	0.810	1.66429	58.29
31	191.15137	DD [31]		
32	25.73095	6.432	1.49700	81.54
33	−147.81297	0.143		
34	30.44264	1.108	1.79036	48.93
35	16.64113	8.538	1.49700	81.54
36	−33.63077	0.376		

TABLE 9-continued

Example 5

Si	Ri	Di	Ndj	νdj
37	−30.15467	0.800	1.75305	47.38
38	−791.72538	6.609		
39	∞	1.000	1.51633	64.14
40	∞	3.500		
41	26.37182	5.113	1.47999	58.75
42	−27.82235	1.125	1.70705	56.15
43	252.69930	3.491		
44	273.83488	0.810	1.62359	60.99
45	10.06816	4.599	1.47999	58.75
46	100.00089	5.000		
47	∞	1.000	1.51633	64.14
48	∞	13.811		

TABLE 10

Example 5

	Wide Angle	Intermediate	Telephoto
Zr	1.0	3.8	36.3
F	11.573	44.462	418.895
F No.	2.67	3.53	6.64
2ω (°)	45.6	11.8	1.2
DD [8]	2.245	37.057	73.521
DD [17]	72.658	37.846	1.382
DD [26]	3.000	17.419	36.356
DD [31]	52.258	37.839	18.902

Example 6

The lens configuration of the variable magnification optical system according to Example 6 is illustrated in FIG. **6**. The configuration of lens groups, the lens groups that move when changing magnification, and the directions of movement thereof in the variable magnification optical system of Example 6 are the same as those of the variable magnification optical system of Example 1.

Only a fourth lens group G**4** moves during focusing operations. When changing focus from that on an object at infinity to that on an object at a proximal distance, the fourth lens group G**4** moves from the object side to the image side. The variable magnification optical system of Example 6 is configured such that the transverse magnification ratio of the fourth lens group G**4** in a state focused on an object at infinity is negative throughout the entire variable magnification range.

A first lens group G**1** is constituted by, in order from the object side to the image side, lenses L**11** through L**15**, a second lens group G**2** is constituted by, in order from the object side to the image side, lenses L**21** through L**25**, and a third lens group G**3** is constituted by, in order from the object side to the image side, lenses L**31** through L**35**. The fourth lens group G**4** is constituted by, in order from the object side to the image side, a negative lens L**41**, which is a single lens, and a cemented lens formed by cementing a positive lens L**42** and a negative lens L**43** together. A fifth lens group G**5** is constituted by, in order from the object side to the image side, lenses L**51** through L**58**. Note that in the example illustrated in FIG. **6**, plane parallel plate shaped optical members PP**1** and PP**2** are respectively provided between the lens L**54** and the lens L**55**, and between the fifth lens group G**5** and an image formation plane Sim. The optical members PP**1** and PP**2** are similar to the optical members PP1 and PP2 illustrated in FIG. 4, and are not essential components of the present disclosure.

Basic lens data are shown in Table 11, various items and variable distances are shown in Table 12, and aberration diagrams for a state focused on an object at infinity are illustrated in FIG. 14 for the variable magnification optical system of Example 6.

TABLE 11

Example 6				
Si	Ri	Di	Ndj	νdj
1	77.46940	2.010	1.58228	61.48
2	52.25773	15.600	1.49700	81.54
3*	−591.25598	0.100		
4	75.17299	2.013	1.70002	49.85
5	42.39625	15.305	1.49700	81.54
6	−314.34196	0.774		
7	−263.09520	2.000	1.69999	56.50
8	191.30947	DD [8]		
9	−182.82925	1.000	1.80001	48.00
10	41.39942	2.676		
11	−58.30015	1.000	1.80001	48.00
12	60.01798	0.200		
13	43.56186	5.917	1.78226	25.89
14	−26.69984	0.810	1.54603	58.18
15	68.47870	1.786		
16	−47.83142	0.938	1.78305	49.69
17	93.99119	DD [17]		
18	296.78033	5.923	1.56793	55.91
19	−15.61915	1.000	1.90000	38.00
20	−50.82936	0.522		
21	927.95754	4.740	1.67995	49.69
22	−26.10032	0.100		
23	64.77623	4.246	1.61644	62.09
24	−29.13696	0.800	1.90001	37.87
25	−164.42336	3.000		
26 (St)	∞	DD [26]		
27	−55.99754	1.167	1.87426	33.39
28	82.82984	0.726		
29	−52.34721	3.748	1.80174	24.91
30	−16.48287	0.810	1.67495	57.69
31	147639.53693	DD [31]		
32	25.85714	6.168	1.49700	81.54
33	−189.98598	0.100		
34	38.09866	1.000	1.80001	39.67
35	18.28098	7.414	1.49700	81.54
36	−57.66796	0.895		
37	−35.29051	0.878	1.59937	64.71
38	−136.22544	3.500		
39	∞	1.000	1.51633	64.14
40	∞	3.500		
41	22.14900	5.552	1.48000	58.75
42	−29.42124	0.810	1.61822	61.81
43	187.64728	3.227		
44	192.60771	0.800	1.71670	55.66
45	9.69194	4.467	1.47999	58.75
46	101.61626	5.000		
47	∞	1.000	1.51633	64.14
48	∞	11.838		

TABLE 12

Example 6			
	Wide Angle	Intermediate	Telephoto
Zr	1.0	3.8	36.3
F	11.537	44.323	417.544
F No.	2.76	3.35	6.30
2ω (°)	45.0	11.6	1.2
DD [8]	2.073	40.347	77.404
DD [17]	76.524	38.250	1.193
DD [26]	3.000	16.130	34.132
DD [31]	55.047	41.917	23.915

Example 7

The lens configuration of the variable magnification optical system according to Example 7 is illustrated in FIG. 7. The configuration of lens groups, the lens groups that move when changing magnification, and the directions of movement thereof in the variable magnification optical system of Example 7 are the same as those of the variable magnification optical system of Example 1.

Only a portion of a fifth lens group G5 moves during focusing operations. In the variable magnification optical system of Example 7, the fifth lens group G5 is constituted by, in order from the object side to the image side, a fifth lens group front group G5A having a positive refractive power, a fifth lens group middle group G5B having a positive refractive power, and a fifth lens group rear group G5C having a negative refractive power. When changing focus from that on an object at infinity to that on an object at a proximal distance, the fifth lens group middle group G5B moves from the image side to the object side, while the fifth lens group front group G5A and the fifth lens group rear group G5C are fixed with respect to an image formation plane Sim.

A first lens group G1 is constituted by, in order from the object side to the image side, lenses L11 through L15, a second lens group G2 is constituted by, in order from the object side to the image side, lenses L21 through L25, and a third lens group G3 is constituted by, in order from the object side to the image side, lenses L31 through L35. A fourth lens group G4 is constituted by, in order from the object side to the image side, lenses L41 through L43. The fifth lens group front group G5A is constituted by, in order from the object side to the image side, lenses L51 through L54, the fifth lens group middle group G5B is constituted by a cemented lens formed by cementing a positive lens L55 and a negative lens L56, provided in this order from the object side to the image side, together, and the fifth lens group rear group G5C is constituted by, in order from the object side to the image side, lenses L57 and L58.

Basic lens data are shown in Table 13, various items and variable distances are shown in Table 14, and aberration diagrams for a state focused on an object at infinity are illustrated in FIG. 15 for the variable magnification optical system of Example 7.

TABLE 13

Example 7				
Si	Ri	Di	Ndj	νdj
1	78.11008	2.010	1.59655	57.09
2	53.97995	14.654	1.49700	81.54
3	−616.58085	0.100		
4	75.39809	2.000	1.69779	51.11
5	41.90456	14.857	1.49700	81.54
6	−311.92458	0.921		
7	−270.28394	2.000	1.67114	57.51
8	189.45833	DD [8]		
9	−217.65944	1.000	1.80000	48.00
10	43.13902	3.179		
11	−62.81492	1.000	1.79206	48.79
12	60.90021	0.200		
13	44.33521	6.539	1.77520	26.24
14	−29.88246	0.810	1.54111	73.68
15	75.89322	4.851		
16	−51.70887	1.042	1.79999	43.05
17	101.85690	DD [17]		
18	196.07246	6.043	1.55754	57.41
19	−16.15615	1.885	1.90001	38.00
20	−55.36655	1.936		
21	2609.21875	4.802	1.68777	44.40
22	−27.34466	0.100		

TABLE 13-continued

Example 7				
Si	Ri	Di	Ndj	νdj
23	62.21277	4.565	1.61130	62.88
24	−30.11022	0.800	1.90001	35.59
25	−172.71494	3.000		
26 (St)	∞	DD [26]		
27	−59.71374	1.037	1.82415	39.16
28	69.57930	0.753		
29	−57.83851	3.887	1.79935	26.41
30	−16.92819	0.810	1.66140	58.43
31	124.86518	DD[31]		
32	28.86728	5.403	1.49700	81.54
33	−104.14424	0.100		
34	45.66787	1.000	1.80001	46.53
35	18.42902	6.235	1.49700	81.54
36	−73.62972	1.205		
37	−31.37855	1.819	1.70672	44.51
38	−46.75502	3.500		
39	∞	1.000	1.51633	64.14
40	∞	16.269		
41	38.44402	4.749	1.59675	58.49
42	−21.96704	1.020	1.65078	34.20
43	−116.24212	3.009		
44	−270.10686	0.800	1.70093	56.45
45	10.44674	4.226	1.57143	41.61
46	99.99640	5.000		
47	∞	1.000	1.51633	64.14
48	∞	12.059		

TABLE 14

Example 7			
	Wide Angle	Intermediate	Telephoto
Zr	1.0	3.8	36.3
F	11.545	44.353	417.873
F No.	2.60	3.41	7.03
2ω (°)	45.2	11.8	1.2
DD [8]	2.133	37.770	72.517
DD [17]	73.033	37.396	2.649
DD [26]	3.000	16.918	42.415
DD [31]	40.866	26.948	1.451

Table 15 shows values corresponding to Conditional Formulae (1) through (8) for Examples 1 through 7. In addition, Table 15 also shows the transverse magnification ratio β4W of the fourth lens group G**4** in a state focused on an object at infinity at the wide angle end and the transverse magnification ratio β4T of the fourth lens group G**4** in a state focused on an object at infinity at the telephoto end. The values shown in Table 15 are related to the d line.

TABLE 15

Formula		Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7
(1)	fT/f2	−26.556	−25.823	−25.089	−25.076	−25.904	−26.712	−25.984
(2)	fT/f1	3.089	3.070	3.127	3.080	3.200	3.043	3.068
(3)	f1/f1C	−0.593	−0.582	−0.326	−0.867	−0.794	−0.869	−0.822
(4)	(L1Cf + L1Cr)/(L1Cf − L1Cr)	0.132	0.121	0.920	0.183	0.126	0.158	0.176
(5)	νAp − νAn	17.44	16.87	7.64	20.82	20.04	20.06	24.46
(6)	(νAp + νAn)/2	72.83	73.11	77.73	71.14	71.52	71.51	69.32
(7)	β5T	−0.262	−0.270	−0.287	−0.509	−0.411	−0.241	−0.416
(8)	β4T/β4W	1.391	1.415	1.431	1.733	1.513	1.237	1.615
	β4W	−4.081	−3.857	−3.544	−1.915	−2.346	−4.420	−2.353
	β4T	−5.675	−5.459	−5.073	−3.319	−3.549	−5.466	−3.800

As can be understood from the above data, the variable magnification optical systems of Examples 1 through 7 have high variable magnification ratios of 36.6×, favorably correct various aberrations, and realize high optical performance. In addition, the variable magnification optical systems of Examples 1 through 7 have long focal lengths of 400 or greater at the telephoto end and small full angles of view of 1.4° or less at the telephoto end, and are favorably suited as variable magnification optical systems of the telephoto type. Note that in the case that the optical systems disclosed in Japanese Unexamined Patent Publication Nos. H9(1997)-325269 and H4(1992)-191811 are employed as comparative examples and the focal lengths of the optical systems disclosed in Japanese Unexamined Patent Publication Nos. H9(1997)-325269 and H4(1992)-191811 are increased by scaling, it is considered that the correction of spherical aberration and longitudinal chromatic aberration at the telephoto end will become insufficient, and that it would be difficult to realize variable magnification optical systems of the telephoto type having high optical performance.

Next, an embodiment of an imaging apparatus of the present disclosure will be described. FIG. **16** is a diagram that schematically illustrates the configuration of an imaging apparatus **10** that employs a variable magnification optical system **1** according to an embodiment of the present disclosure as an example of an imaging apparatus according to an embodiment of the present disclosure. Examples of the imaging apparatus **10** include, for example, a surveillance camera, a video camera, an electronic still camera, etc.

The imaging apparatus **10** is equipped with the variable magnification optical system **1**, a filter **7** provided at the image side of the variable magnification optical system **1**, an imaging element **8** that captures images of subjects which are formed by the variable magnification optical system, a signal processing section **4** that processes signals output from the imaging element **8**, a variable magnification control section **5** for changing the magnification of the variable magnification optical system **1**, and a focus control section **6** for performing focusing operations of the variable magnification optical system **1**. FIG. **16** illustrates an example in which the variable magnification optical system **1** is constituted by a first lens group G**1** through a fifth lens group G**5**. Each of the lens groups are illustrated conceptually. The imaging element **8** captures images of subjects formed by the variable magnification optical system **1** and converts the captured images into electrical signals. The imaging element **8** is provided such that the image capturing surface thereof matches the image formation plane of the variable magnification optical system **1**. A CCD (Charge Coupled Device), a CMOS (Complementary Metal Oxide Semiconductor) or the like may be employed as the imaging element **8**. Note that only one imaging element **8** is illustrated in FIG. **16**. However, the imaging apparatus of the present disclosure is not limited to such a configuration, and may be an imaging apparatus of the so called three plate format, which has three imaging elements.

The present disclosure has been described with reference to the embodiments and Examples thereof. However, the variable magnification optical system of the present disclosure is not limited to the embodiments and Examples described above, and various modifications are possible. For example, the values of the radii of curvature of each lens, the distances among surfaces, the refractive indices, and the Abbe's numbers may be different values.

What is claimed is:

1. A variable magnification optical system consisting of, in order from the object side to the image side:

a first lens group having a positive refractive power, which is fixed with respect to an image formation plane when changing magnification;

a second lens group having a negative refractive power that moves from the object side to the image side when changing magnification from the wide angle end to the telephoto end; and

a rearward lens group having a positive refractive power throughout the entire variable magnification range that includes at least one lens group that moves when changing magnification, the distance between the rearward lens group and the second lens group changing when changing magnification;

the first lens group consisting of, in order from the object side to the image side, a first lens group front group having a positive refractive power, a first lens group middle group having a positive refractive power, and a first lens group rear group having a negative refractive power;

the first lens group front group consisting of a cemented lens formed by cementing a negative lens and a positive lens, provided in this order from the object side to the image side, together, the coupling surface of this cemented lens being convex toward the object side, and the surface most toward the object side within the first lens group front group being convex;

the first lens group middle group consisting of a cemented lens formed by cementing a negative lens and a positive lens, provided in this order from the object side to the image side, together, the coupling surface of this cemented lens being convex toward the object side, and the surface most toward the object side within the first lens group middle group being convex;

the first lens group rear group consisting of one negative lens;

Conditional Formula (1) below being satisfied:

$$-50<fT/f2<-10 \quad (1)$$

wherein fT is the focal length of the entire optical system at the telephoto end, and f**2** is the focal length of the second lens group; and

Conditional Formula (2) below being satisfied:

$$2<fT/f1<5 \quad (2)$$

wherein f**1** is the focal length of the first lens group.

2. A variable magnification optical system as defined in claim **1**, in which Conditional Formula (2-1) below is satisfied:

$$2.5<fT/f1<3.5 \quad (2\text{-}1).$$

3. A variable magnification optical system as defined in claim **1**, in which Conditional Formula (3) below is satisfied:

$$-1.5<f1/f1C<-0.3 \quad (3)$$

wherein f**1** is the focal length of the first lens group, and f1C is the focal length of the first lens group rear group.

4. A variable magnification optical system as defined in claim **3**, in which Conditional Formula (3-1) below is satisfied:

$$-1<f1/f1C<-0.5 \quad (3\text{-}1).$$

5. A variable magnification optical system as defined in claim **1**, in which Conditional Formula (4) below is satisfied:

$$0<(L1Cf+L1Cr)/(L1Cf-L1Cr)<0.95 \quad (4)$$

wherein L1Cf is the radius of curvature of the surface toward the object side of the negative lens of the first lens group rear group, and L**1**Cr is the radius of curvature of the surface toward the image side of the negative lens of the first lens group rear group.

6. A variable magnification optical system as defined in claim **5**, in which Conditional Formula (4-1) below is satisfied:

$$0.05<(L1Cf+L1Cr)/(L1Cf-L1Cr)<0.5 \quad (4\text{-}1).$$

7. A variable magnification optical system as defined in claim **1**, in which Conditional Formulae (5) and (6) below are satisfied:

$$0<\nu Ap-\nu An<35 \quad (5)$$

$$60<(\nu Ap+\nu An)/2<90 \quad (6)$$

wherein νAp is the Abbe's number with respect to the d line of the positive lens within the first lens group front group, and νAn is the Abbe's number with respect to the d line of the negative lens within the first lens group front group.

8. A variable magnification optical system as defined in claim **7**, in which Conditional Formula (5-1) below is satisfied:

$$5<\nu Ap-\nu An<30 \quad (5\text{-}1).$$

9. A variable magnification optical system as defined in claim **7**, in which Conditional Formula (6-1) below is satisfied:

$$65<(\nu Ap+\nu An)/2<80 \quad (6\text{-}1).$$

10. A variable magnification optical system as defined in claim **1**, wherein:

the rearward lens group consists of, in order from the object side to the image side:

a third lens group having a positive refractive power which is fixed with respect to the image formation plane when changing magnification;

a fourth lens group having a negative refractive power which moves when changing magnification; and

a fifth lens group having a positive refractive power, the distance between the fourth lens group and the fifth length group changing when changing magnification.

11. A variable magnification optical system as defined in claim **10**, wherein:

a stop which is fixed with respect to the image formation plane when changing magnification is provided.

12. A variable magnification optical system as defined in claim **10**, in which Conditional Formula (7) below is satisfied:

$$-1<\beta 5T<0 \quad (7)$$

wherein β5T is the transverse magnification ratio of the fifth lens group in a state focused on an object at infinity at the telephoto end.

13. A variable magnification optical system as defined in claim **12**, in which Conditional Formula (7-1) below is satisfied:

$$-0.6<\beta 5T<-0.2 \quad (7\text{-}1).$$

14. A variable magnification optical system as defined in claim **10**, in which Conditional Formula (8) below is satisfied:

$$1.15<\beta 4T/\beta 4W<3 \quad (8)$$

wherein β4T is the transverse magnification ratio of the fourth lens group in a state focused on an object at infinity at the telephoto end, and β4W is the transverse magnification ratio of the fourth lens group in a state focused on an object at infinity at the wide angle end.

15. A variable magnification optical system as defined in claim **14**, in which Conditional Formula (8-1) below is satisfied:

$$1.2<\beta 4T/\beta 4W<2 \quad (8\text{-}1).$$

16. A variable magnification optical system as defined in claim **10**, wherein:

the fifth lens group is fixed with respect to the image formation plane when changing magnification.

17. A variable magnification optical system as defined in claim **1**, in which Conditional Formula (1-2) below is satisfied:

$$-40<fT/f2<-15 \quad (1\text{-}2).$$

18. An imaging apparatus equipped with a variable magnification optical system as defined in claim **1**.

* * * * *